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# Computer Aided Control of Sequential Ion Beam Deposition of Binary Alloy Thin Films

by

Jaeshin Ahn

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
OF DOCTOR of PHILOSOPHY

Department of Electrical Engineering

EDMONTON, ALBERTA
Spring 1986

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Date March 17, 1986

## Dedication

*To my wife Taehui and*

*to my children Henry, Janey and Roger.*

*Without their encouragement and patience this work would never have been completed.*

# Abstract

The growth of a metastable binary alloy film by a low energy sequential ion beam has been formulated using a modified atomic mixing theory. A conventional electron impact ion source has been modified to be used as an ion source for binary alloys by adding a second furnace. A new operating mode of electron impact ion source: constant discharge current and voltage has been realized with the aid of computer control of ion source operation. This new mode with feedback control provides higher ion extraction and better stability when compared with conventional modes. A microprocessor-based data acquisition and control system using a master-slave configuration has been designed and built to handle the sequential deposition of two elemental ion beams. A host computer is interfaced with the slave system as a control console for the ion beam system. An operating system for the slave system has been written to execute multichannel data acquisition and control of sequential ion beam deposition. For the host computer operation, two separate softwares have been written: one for ion source outgassing and another for sequential ion beam deposition and data handling. Binary alloy thin films of Pb and Mg have been produced by sequential ion beam deposition and analyzed with Rutherford backscattering, scanning electron microscopy and transmission electron microscopy. The results of analysis show that metastable binary alloys can be produced by this new technique with excellent control

over their composition.

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I wish to thank my supervisors, Dr. R.P.W. Lawson and Dr. K.A. Stromsmoe for their help and encouragement during the course of this work and throughout the writing of this thesis.

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# Table of Contents

Chapter Page

I. Introduction ........................................1

II. The Low Energy Ion Beam Deposition Technique ......7

A. Two-body collision kinematics ...................7

B. Collision probability ..........................10

C. The penetration and damage region ..............16

D. Ejection of particles from the substrate ......17

III. Metastable Binary Alloy Thin Film Deposition using a Sequential Ion Beam Technique ............21

A. Introduction ...................................21

B. Atomic mixing with low energy sequential ion beams ...............................................27

C. Film growth using atomic mixing at and in surface layer .....................................29

IV. Hot Cathode Electron Impact Ion Source ...........43

A. Introduction ...................................43

B. Ion source operational parameters analysis ....46

C. The effect of ion source operational parameters on the cathode sheath thickness ....48

D. The maintenance of high plasma density ........55

E. Ion source operation with constant discharge current and potential .........................61

Introduction ..............................61

Ionization efficiency and discharge potential .................................63

PID control of ion source ..................66

Results and discussion ....................68

V. System Hardware Specification and Design .........74

A. Introduction ...................................74

B. Ion beam system ...............................75

C. Data acquisition and control system ..........92

VI. Software Development for Sequential Ion Beam Deposition ..................................107

A. The microprocessor operating routine .........107

B. Start-up/Shut down and outgassing routine ....112

C. Master operating program ....................112

VII. Binary Alloy Thin Film Production and Analysis ..115

A. Introduction ................................115

B. Ion source preparation ......................116

C. Ion source charge material selection .........121

D. Ion mass selection and focusing(Colutron E X B mass filter) .............................124

E. Pb/Mg binary alloy deposition parameters .....126

F. Pb/Mg alloy thin film analysis by RBS ........127

G. Analysis by SEM and TEM ......................145

VIII. Limitations of the Present System ..............162

IX. Conclusions .....................................164

A. Sequential ion beam deposition system ........164

B. Pb/Mg binary alloy thin film deposition ......166

X. References ......................................167

XI. APPENDIX I .....................................178

XII. APPENDIX II ....................................208

XIII. APPENDIX III ...................................243

XIV. VITA ............................................256

## List of Tables

| Table | Description | Page |
|---|---|---|
| 7-1 | Ion source filament specifications | 120 |
| 7-2 | Synthesized RBS spectrum with area, height and width ratio of different composite of Pb/Mg/O. | 137 |
| 7-3 | The comparison of TEM diffraction pattern of $Pb^+$ ion beam deposited film with ASTM data. | 148 |
| 7-4 | The comparison of TEM diffraction pattern of $Mg^+$ ion beam deposited film with ASTM data. | 149 |

# List of Figures

Page
Figure 2-1 Two-body collision model 9
Figure 2-2a Energy transfer and scattering density -1 14
Figure 2-2b Energy transfer and scattering density -2 14
Figure 2-2c Energy transfer and scattering density -3 15
Figure 2-2d Energy transfer and scattering density -4 15
Figure 2-3 Sputtering yield near threshold energy -1 19
Figure 2-4 Sputtering yield near threshold energy -2 19
Figure 3-1 The block diagram of sequential ion beam deposition. 27
Figure 3-2 Pb/Mg binary alloy atomic concentration. 33
Figure 3-3 Ion range diagram of 50 eV Ge$^{+}$ onto poly Ge. 38
Figure 3-4a Pb/Mg binary alloy composition spectrum(1) 39
Figure 3-4b Pb/Mg binary alloy composition spectrum(2) 40
Figure 3-4c Pb/Mg binary alloy composition spectrum(3) 41
Figure 3-4d Pb/Mg binary alloy composition spectrum(4) 42
Figure 4-1 Ion source with two serial furnaces. 44
Figure 4-2 Potential and field diagram of hot cathode electron impact ion source. 48
Figure 4-3 Charge flow between cathode and anode in an electron impact ion source. 50
Figure 4-4 Electron ionization coefficient. 60
Figure 4-5 Ion source discharge potential vs. filament current. 65
Figure 4-6 Ion source PID control. 66
Figure 4-7a Ion source discharge potential control -1 69

Figure 4-7b Ion source discharge potential control -2 70
Figure 4-7c Ion source discharge potential control -3 71
Figure 4-8 Ion beam current without ion source PID control. 72
Figure 4-9 Ion beam current with ion source PID control. 73
Figure 5-1 The block diagram of ion beam system. 78
Figure 5-2 Decelerator and target assembly. 80
Figure 5-3 Ion trajectories and equipotential lines with a cylindrical decelerator. 83
Figure 5-4 Ion trajectories and equipotential lines with a 150° conical decelerator. 84
Figure 5-5a Ion trajectories with a 60° conical decelerator. 86
Figure 5-5b Ion trajectories with a 90° conical decelerator. 86
Figure 5-5c Ion trajectories with a 60° conical decelerator and long target box. 87
Figure 5-5d Ion trajectories with a cylindrical decelerator with a diverging beam. 87
Figure 5-6 Ion current vs. decelerator potential. 88
Figure 5-7 Ion beam energy spread with different ion source operating conditions. 89
Figure 5-8 Ion source extraction potential vs. extracted ion current. 91
Figure 5-9 The block diagram of data acquisition and control system. 93

Figure 5-10 The block diagram of slave computer. 95

Figure 5-11 The block diagram of A/D unit and multiplexer. 98

Figure 5-12 The block diagram of D/A unit. 101

Figure 5-13 D/A resolution increase with two D/A units in series. 103

Figure 5-14 The block diagram of AC load control unit and multiplexer. 106

Figure 6-1 The flow diagram of slave system operation. 108

Figure 6-2 The timing diagram of sequential ion beam. 109

Figure 6-3 The diagram of ion beam switching routine. 111

Figure 6-4 Master operating program information display formats 114

Figure 7-1 Ion source chamber pressure vs. ion source outgassing speed -1 118

Figure 7-2 Ion source chamber pressure vs. ion source outgassing speed -2 119

Figure 7-3 Source filament connection and failure spot. 121

Figure 7-4 Vapor pressure characteristics of prospective ion source materials. 123

Figure 7-5 Mass selection magnet current chart with different E-field set-up. 124

Figure 7-6 A schematic presentation of backscattered particle energy from a thin slab target. 129

Figure 7-7 RBS data collection instrumentation set-up. 138

Figure 7-8 RBS spectrum from Pb/Mg(25/75%) ion beam deposited film. 141

Figure 7-9 RBS spectrum from Pb/Mg(50/50%) ion beam deposited film - 1. 142

Figure 7-10 RBS spectrum from PB/Mg(50/50%) ion beam deposited film - 2. 143

Figure 7-11 RBS spectrum from Pb/Mg(75/25%) ion beam deposited film. 144

## List of Photographic Plates

| Plate | Description | Page |
|---|---|---|
| 1 | SEM surface topography of 50 eV $Pb^+/Mg^+$(50/50%) ion beam deposited alloy film. | 152 |
| 2 | SEM cross section topography of 50 eV $Pb^+/Mg^+$ (50/50 %) ion beam deposited alloy film. | 154 |
| 3 | TEM diffraction pattern of 50 eV $Pb^+$ ion beam deposited film. | 156 |
| 4 | TEM diffraction pattern of 50 eV $Mg^+$ ion beam deposited film. | 158 |
| 5 | TEM diffraction pattern of 50 eV $Pb^+/Mg^+$(50/50%) ion beam deposited alloy film. | 160 |

# I. Introduction

The demand for the applications of ion beams to material modification and material growth has increased in parallel with the industrial demand for new materials having improved characteristics for adverse environments. Especially in the rapidly advancing microelectronics device technology, the use of ion beams in the device manufacturing process has become an essential technology. As well as in microelectronics device applications, ion beam technology is used in other industrial applications. They are: optical coating, wear resistant tool or machine components, metallized films, metallized plastics or textiles, coated window glass or iron sheet and so on.

In recent years, high energy ion beams have been used to produce metastable alloys which exceed the conventional solubility limits(*1-6). Multiple target sputtering deposition(*7,8,9), high dose ion implantation(*10) and ion beam mixing(*1-6,11-13) have been the generally accepted techniques used to date to make metastable alloys.

The low energy ion beam deposition technique is known to have an inherent superior controllability of its beam energy, beam purity and resulting thickness in the growing film(*14-26). The advantages of the low energy ion beam deposition technique over conventional techniques such as thermal evaporation (which includes molecular beam epitaxy) and sputtering in metastable alloy film deposition, can be summarized as follows :

a. high particle energy (50 eV) : controllable and high energy contributes to good film adhesion to substrate, allowing intermixing of alloy elements.
b. high beam purity : ion beam mass filtering and ultra high vacuum environment contributes to the high purity of each alloy element.
c. beam directionality : focusing and scanning of beam contributes to good film thickness distribution.
d. the precise monitoring of the quantity of deposited ions to control the composition of the alloy and the film thickness is made possible through the specification of ion dose and beam density.

It was conceived that a metastable alloy could be formed if an ion beam of multiple elements could be deposited onto a common substrate simultaneously or sequentially. The alloy composition ratio could be controlled by the deposition dosage of each different ion beam. A binary alloy system has been implemented here mainly to investigate the feasibility of the technique but also to reduce the complexity of the system.

The present work describes a deposition system for growing films of binary alloys set up by converting a conventional low energy ion beam deposition system which was designed by P. Bryce(*14) in 1970. Planning for the conversion started with the preliminary study of two different modes of binary deposition system ; a co-deposition mode and a sequential deposition mode. The sequential deposition mode has been selected because of the lower cost for system set-up. The co-deposition mode has simpler system operation and higher deposition efficiency when compared with the sequential mode, but the former requires two identical ion beam lines which are aligned onto a common substrate. The cost of such an ion beam system then becomes almost twice that of a sequential system.

The conversion involved four major design procedures ;

a. data acquisition and control system hardware design.

b. software development for slave and host computer operation.

c. modification of the ion source to produce ion beams of two different species

d. modification of conventional power supplies to be interfaced with computer controls.

Data acquisition and control protocol for the sequential ion beam deposition system is essential to execute the sequential operation which involves switching a number of ion beam controls from one set to another in a short period.

The requirement of high voltage isolation of 7.5 kV on A/D and D/A units became a crucial factor in determining whether to buy off-the shelf multichannel data acquisition and control systems or to design one to meet the requirements of the existing system. At the time of this consideration(1981), no commercial multichannel data acquisition and control systems with such a high voltage isolation rating were available. Therefore, an 8-bit microprocessor-based system with 7.5 kV isolation rated components was designed and built to handle the requirements of the sequential ion beam deposition system.

In Chapter II, the interactions between a stationary target and a projectile having kinetic energy equivalent to the ion beam deposition energy are described in detail to visualize the amount of energy transferred and the low possibility of lattice atom removal at such a low incident energy.

In Chapter III, a new concept of atomic mixing theory applicable to the film growth by low energy ion beam deposition is described. A computer simulation based on this theory is presented using binary alloy deposition by sequential ion beams.

Optimum operation of an ion source is an important factor in determining ion beam system efficiency. To help understand the effects of ion source parameters on the operation of an ion source, an analysis of the parameters of the ion source with the physical dimensions and operating conditions used in this work is given in Chapter IV. The application of real time computer control facilitates the conception and implementation of a new mode of ion source operation : that of constant discharge current together with a constant discharge voltage mode. The new mode permits the extraction of higher ion beam currents compared with the two conventional modes : constant discharge voltage mode or constant discharge current mode. A detailed implementation with results of ion beam extraction under the new mode are discussed in Chapter IV.

In Chapter V, the hardware features of the sequential ion beam deposition system are described. First, the ion beam system characteristics are discussed, emphasising a new geometry of decelerator electrodes at the target(film deposition) end which was designed by computer simulation. Second, the microprocessor-based data acquisition and control system is described.

In Chapter VI, a software protocol for the microprocessor-based system (slave computer) to handle front end units of A/D, D/A and AC load controllers, and one for IBM PC (host computer) to behave as a control console for the sequential ion beam deposition system are described.

In Chapter VII, the alloy film production and analysis are covered. In the first section, system operational parameters used during film production are discussed. The main elements used in this experiment are Pb and Mg. The resulting alloys have been investigated with Rutherford backscattering, scanning electron microscopy and transmission electron microscopy. In the later section, the application of RBS technique to the analysis of alloy films is discussed and the results of film analysis are also described in this chapter. Also, results by SEM and TEM techniques are described.

Chapter VIII discusses the limitations of the present system and recommendations for future improvements.

Chapter IX summarizes the significance of the present work.

The current state of the computer control programs are reproduced in the appendices.

## II. The Low Energy Ion Beam Deposition Technique

The interaction of an energetic ion with a solid involves a number of different processes. Depending on the energy of the incident ion, the interaction between the ion and the substrate can be divided into three categories; 1) the ion can penetrate into the substrate and rest deep in the substrate. 2) the incident ion can sputter a number of surface atoms before it comes to rest near the surface region. 3) it can reside on the surface with a very low probability of ejecting surface atoms.

In each of the above three categories, the ion transfers its kinetic and potential energy to the substrate lattice atoms. The ejection of atoms, ions, electrons and photons, and the displacements of atoms are the major processes occurring during the energy transfer process. Many of these processes are utilized in materials science to develop or improve material characteristics, or to analyze an unknown material by monitoring the interaction between the known incident ion and the target. These process will be discussed in more detail in the next sections.

### A. Two-body collision kinematics

When an energetic atom collides with a stationary atom, one can expect the change of kinetic energy of both atoms, or the excitation and ionization of the incident or target atom. When the energy spent on the latter two processes is negligible compared with the kinetic energy change of the target atom, the collision is considered elastic. The inelastic collision process becomes significant only when the incident atom energy is in the range of $A_1$ KeV , where $A_1$ is the atomic number of the incident atom(*1). The model within the energy range of 10 - 300 eV of low energy ion beam deposition is therefore considered as an elastic collision process. When an incident ion beam of mass $M_1$ and energy $E_0$ collides with a stationary atom of mass $M_2$, then the energy T, transferred to the stationary atom is given by(Figure 2-1),

$$T=4M_1M_2\ (M_1+M_2)^{-2}\ E_0\ \cos^2\theta \text{ ----------------(2-1)}$$

where

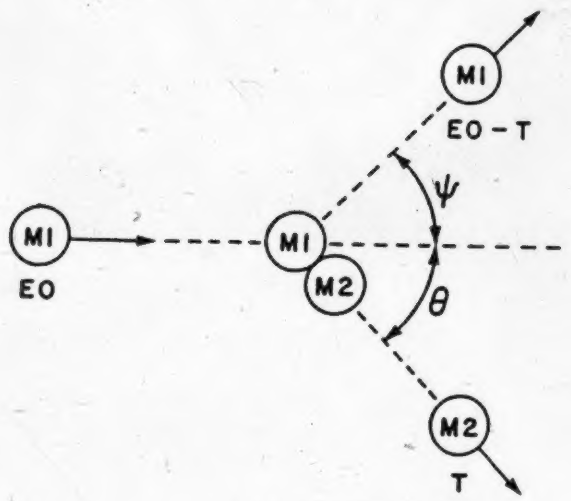
$\theta$ is the target atom scattering angle.

It is obvious that in the head-on collision where $\theta$ =0°, the maximum energy transfer occurs. The maximum energy transfer is given by,

$$T=4M_1M_2\ (M_1+M_2)^{-2}\ E_0 \text{ ----------------- (2-2)}$$

The minimum energy transfer occurs at the grazing angle of $\theta$=90°. The deflection angle of projectile $\psi$, is given by(*1),

$$\psi=\tan^{-1}[M_2\sin2\theta/\ (M_1-M_2\cos2\theta)] \text{ ------- (2-3)}$$



M1 : PROJECTILE MASS
M2 : TARGET ATOM MASS
EO : PROJECTILE ENERGY BEFORE COLLISION
T : TARGET ATOM ENERGY AFTER COLLISION
$\theta$ : TARGET ATOM SCATTERING ANGLE
$\psi$ : PROJECTILE DEFLECTION ANGLE

Figure 2-1. Two-body collision model

## B. Collision probability

It is necessary here to introduce the scattering cross section to describe the probability of an atomic collision. When an energetic incident ion moves towards a target, it may be considered that the incident ion sees the target as a collection of many solid "balls" scattered around, with spaces between each ball. If the ball diameter is large and the space between balls is small, then the probability of collision will be high. The ball "size" seen by the incident particle may be considered to vary as the incident particle energy changes.

Generally the higher the incident energy, the smaller is the effective ball size resulting in a lower collision probability. Because the cross section is a function of incident particle energy, it is convenient to express it in the form of a differential cross section with respect to energy. The ball size is determined by the interatomic forces when the incident particle moves closer to a target atom.

Early studies about the interatomic forces were based on the Coulomb potential which is inversely proportional to the interatomic distance r. The screening effect of the orbital electrons has been introduced into the Bohr, Born-Mayer and Thomas-Fermi interatomic potential models; Lindhard, Scharff and Schiott have refined the cross section theory using the Thomas-Fermi model(*2). Among different interatomic potential models, the Thomas-Fermi potential with a well defined power approximation has been used most commonly nowadays to derive the scattering cross section. The cross section $\sigma$ with power parameter m is given by(*3),

$$d\sigma/dT = C_m E^{-m}T^{-m-1} \text{ --------------- } (2\text{-}4)$$

where

m = power parameter

The power parameter has to be selected according to the incident particle energy. From Sigmund's work(*3), the power parameter m for the energy range of low energy ion beam deposition is assumed to be zero. Then the resulting cross section equation for the low energy particle is given by,

$$d\sigma/dT = C_0/T \text{ ----------------- } (2\text{-}5)$$

where

$C_0=0.5\ \pi\ \lambda_0 a^2$

$\lambda_0=24$

$a=0.885a_0(Z_1{}^{2/3}+Z_2{}^{2/3})^{-1/2}$

The cross section for a low energy collision partner with Pb and Mg becomes,

$$d\sigma/dT=0.343/T\ (10^{-16}\text{cm}^2/\text{eV}) \text{ --------- } (2\text{-}6)$$

By integrating equation 2-5 with $\theta$ and deriving a relationship between target scattering angle $\theta$ and the cross section $\sigma$, the $\theta$ is given by,

$$\theta=\cos^{-1}(K^{1-y})^{-1/2} \text{ -------------- } (2\text{-}7)$$

where

$K=4M_1M_2E_0\ (M_1+M_2)^{-2}$

y : target atom scattering probability

From equation 2-6 and Fig. 2-1 the maximum scattering angle of target atom occurs at $\psi=0°$, i.e. at the minimum possible glancing angle collision.

The projectile will have minimum deflection angle after minimum glancing angle collision with the target atom. From equations 2-1 and 2-6, the proposed "prohibited angle" of projectile deflection becomes,

$$\psi_{min}=\tan^{-1}\{(1+A)[4AE_0\ (1+A)^{-2}-1]^{1/2}\ (2E_0-A-1)^{-1}\} \text{ ----} (2\text{-}8)$$

where

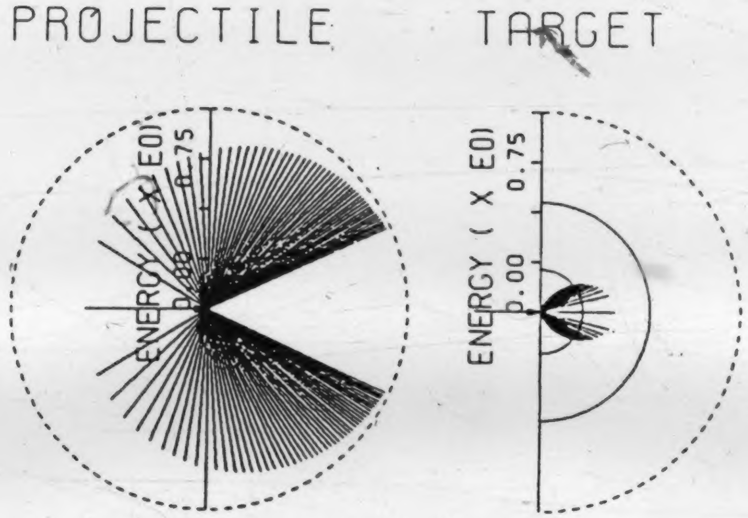
$A=M_2/M_1$

Computer simulation of the collision process aids the visualization of energy and direction of both particles after the projectile ion of 50eV energy collides with the target atom. From equations 2-3 and 2-7, the target atom scattering angle $\theta$ and projectile deflection angle $\psi$ are calculated as scattering probability y is incremented in steps of 1 %. New target atom and projectile energies after collision are also calculated. The pictorial presentation is for the line length as energy and the line spacing as scattering probability(1.0%). Figures 2-2a - 2d show the particle mass dependence on energy and the scattering angular density of target and projectile deflection after collision.

The prohibited angle of projectile deflection after collision becomes larger as the mass ratio of target and projectile increases and/or the projectile energy is lowered. Especially this relation is strong when the projectile is lighter than the target atom. The projectile deflection with the highest probability is right above the prohibited angle, as indicated by the closely-spaced lines of scattering probability. The density of lines describing probability distribution increases as the mass ratio of target and projectile decreases and/or the projectile initial energy increases.

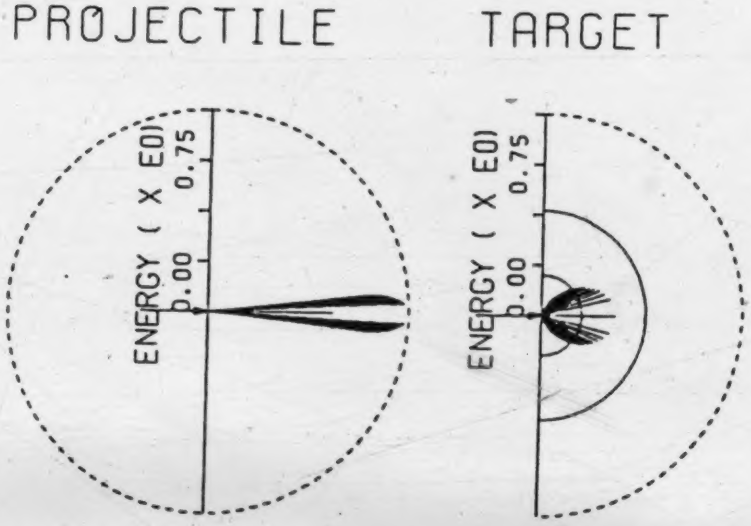
The energy transfer to the target after collision becomes smaller when the mass ratio of heavy atom and light atom becomes larger regardless of which is target or projectile. When a heavy projectile collides with a light target atom, the trajectory of the projectile is hardly affected. For the reverse case of target and projectile, the light projectile is deflected with a wide distribution of probability backwards as well as forwards.

The displacement probability of the target atom is described by the minimum displacement energy $E_{dmin}$ where probability is zero, and full displacement energy $E_s(\simeq 2.6E_{dmin})$ where probability is one and the displacement probability varies linearly between $E_{dmin}$ and $E_s$(*4). The small semi-circle in Figure 2-2a - 2d is for minimum displacement energy, $E_{dmin}$ and the large semi-circle is for



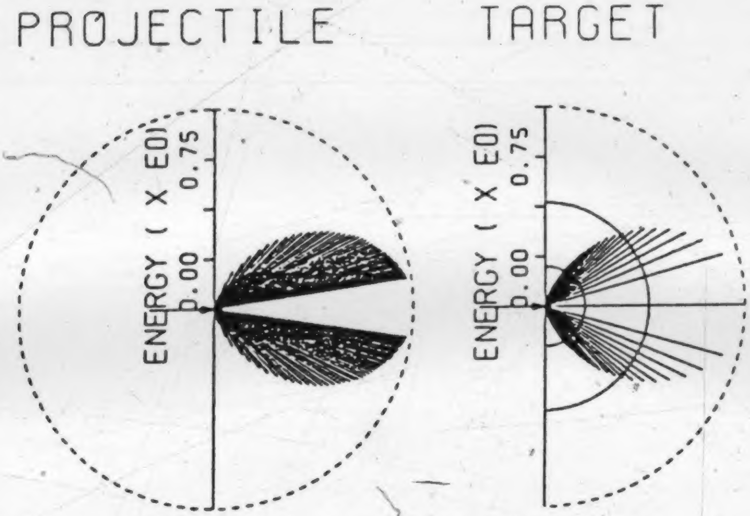
50eV Mg$^{+}$ to Pb target

Figure 2-2a. Energy transfer and scattering density -1



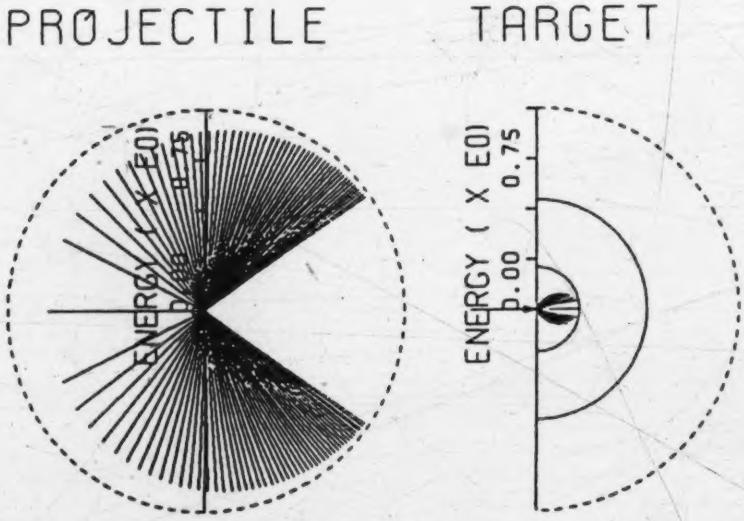
50eV Pb$^{+}$ to Mg target

Figure 2-2b. Energy transfer and scattering density -2



50eV incoming ion to like mass target

Figure 2-2c. Energy transfer and scattering density -3



50eV C+ to Pb target

Figure 2-2d. Energy transfer and scattering density -4

full displacement energy, $E_d$(*5). The collision between a projectile and a target atom with identical mass shows that a considerable fraction of target atoms receive more than $E_d$ and the majority of the projectiles retain a large portion of their initial energy after collision.

When considering alloy deposition using a low energy ion beam and a large mass ratio between projectile and target, the major mixing mechanism relies on the projected range distribution of the incoming particles. The ballistic mixing mechanism involving target lattice disruption is minor. With equal or similar mass alloy constituents, the portion of target lattice atoms displaced by the collision is large. Ballistic mixing then becomes as significant as the projectile projected range distribution in determining the spatial disposition of the alloy constituents.

## C. The penetration and damage region

The incident ion transfers its potential and kinetic energy to the lattice atoms through successive collisions before it rests, and the depth range where it finally rests can be described by a certain distribution function. There is a wide range of data available for a number of different incident atoms and various target atoms over a wide range of energies, but the data are lacking for extreme low energies of less than 300 eV. However, the mean range of 500 eV $Xe^+$ in W was reported to be approximately 5 A°(*6). A report of computer simulation results with 50 eV $Ag^+$ onto Si(111) shows the most probable penetration is about 5 A° (*7). The same computer simulation report with 50 eV $Ge^+$ onto Si(111), 50 eV $Ag^+$ onto Ag(111), 50 eV $Ge^+$ onto Ge(111), 50 eV $Ge^+$ onto Ge poly, shows the penetration depth distribution stays below 10 A°. With 125 eV $Ge^+$ onto Si(111) and 125 eV $Ge^+$ onto Ge poly shows the highest probable penetration depth about 8 A° and the upper bound of distribution reaches to about 12 A°(*7). Generally speaking, the penetration and substrate damage by low eV energy ions is limited to one to two atomic layers below the surface.

## D. Ejection of particles from the substrate

The major ejection mechanism from a substrate by collisions between incident ions and substrate atoms is called sputtering. The sputtering yield is a function of incident ion energy, incident ion mass, target atom mass and incident angle. Many ingenious methods have been developed to measure the sputtering threshold energy(*8). One of the results shows that the threshold energy varies as a function of the heat of sublimation of the target material for $He^+$ and $Ar^+$ bombardment(*9).

Near the threshold energy region, the sputtering yield measurements show two different slopes(*10,11): one with low slope which starts at the threshold energy and stretches over about 50 eV energy and another with steep slope which starts at the end of low slope and increases rapidly as energy is increased. Henschke(*12) has proposed that the low slope near the threshold region describes a "minimum-band" threshold where small energy is required to release an atom which is isolated and lies above a full plane of target atoms. The steep slope at the end of the "minimum-band" threshold can be described as the "full-plane" threshold where larger energy is required to eject an atom from a complete crystal plane(Figure 2-3,2-4).

According to Henschke's two different threshold energy proposal, it is very likely that the self-sputtering yield in the process of film growth by a low energy ion beam would be higher than the one with a bulk material target with the same energy ion beam, because there would be more isolated atoms on the growing film than on the bulk material. By reducing the energy of the ion beam below the "minimum-band" threshold, the self-sputtering can be minimized but the ion loss due to the space charge expansion increases rapidly at the extreme low ion energy. Therefore the optimum ion energy has to be selected by considering both the self-sputtering and the space charge expansion. The proposed ion deposition rate f(E) at ion energy E becomes,

$$f(E) = I(E)\,[1 - \gamma(E)] \text{ -----------(2-9)}$$

where

$I(E)$ ; ion current measured at target(ion arrival rate)

$\gamma(E)$; self-sputtering coefficient

$1-\gamma(E)$ ; ion sticking coefficient

There are available data of the self-sputtering coefficient

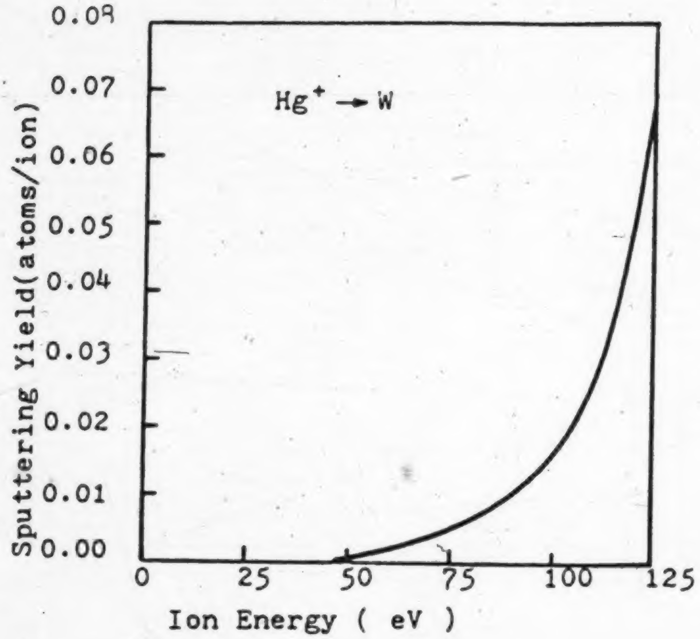


Figure 2-3. Sputtering yield near threshold energy-1 (*11)

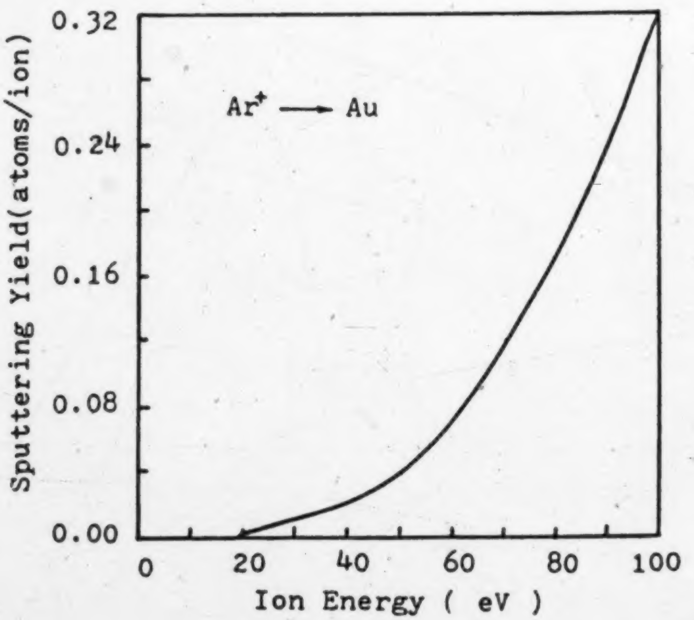


Figure 2-4. Sputtering yield near threshold energy-2 (*10)

on various elements but most reports do not include the extreme low energy region of interest for low energy ion beam deposition(*13,14,15). When an alloy target is used, the sputtering can cause a surface composition change due to the differing sputtering coefficients of alloy elements. Therefore in the process of alloy deposition using ion beams, further caution has to be taken to keep target sputtering to a minimum even at the cost of deposition efficiency.

The importance of secondary electron emission in the ion beam experiment is that the ion current measurement accuracy is greatly dependent on the control of the secondary electron emission. In the low energy ion beam deposition system, the secondary electron emission is not affecting ion current measurement on the target because the geometry of the ion deceleration system in the target chamber acts as a secondary electron supressor with an equivalent high suppressor potential.

# III. Metastable Binary Alloy Thin Film Deposition using a Sequential Ion Beam Technique

## A. Introduction

Chapter II discussed the kinematics of projectile-target collision processes and introduced the concept of energy exchange between a single incoming projectile as it slowed down within a solid target comprised of individual atoms. Of course, any film deposition method uses a flux comprising a large number of incoming particles. Chapter III therefore is concerned with the mechanism of film growth using such a collective beam of low energy particles. Recent theoretical work has to be extended and modified here to accommodate extremely low energy incident particles in a film growth mechanism.

7

Initially, however, a brief review of established ion beam techniques is presented in order to stress the essential differences between these and the low energy concepts comprising this thesis.

Recent developments of interest in the formation of metastable materials have been enhanced with the application of high energy ion beams. Sputtering of multiple targets onto a common substrate is an example of metastable material formation which has been reported in earlier works(*1,2,3). Moreover, irradiating layered films of different material with a high energy ion beam causes mixing of layered material into each other. The ion beam mixing techniques have been investigated by many researchers in recent years(*4,5,6,7). Also a metastable alloy has been reported from an equilibrium alloy after the surfaces are bombarded with energetic ions(*8). The high fluence ion implantation under carefully controlled conditions can produce localized metastable alloys.

The aforementioned techniques in producing metastable alloys lack the precise control over alloy composition. A conventional technique of controlling the alloy composition ratio using multiple sputtering targets(co-sputtering) mainly relies on the target area ratio and sputtering coefficients of target elements. Moreover, adding a high energy ion beam mixing process introduces more variables. The composition profile of the alloy after the mixing process is dependent on a number of different parameters: ion beam energy, projectile ion mass, ion fluence, substrate temperature, the mass of atom to be relocated and the mass of the host lattice. Unfortunately, sputtering adds a further complication especially when a high fluence ion beam is applied : the desired material actually erodes. Due to the limitation in the projected range of energetic ions, the depth of any ion beam mixing process is restricted. Because a third species is usually used as the projectile ion in ion beam mixing, the processed alloy also contains considerable portions of the injected ion species.

A metastable alloy formed by ion bombardment of an equilibrium alloy is dependent on preferential sputtering and displacement mixing, and these are effective only at the near surface region. The dopant profile of low fluence ion implantation approximates a Gaussian distribution; at the high dose and high dose rates which are commonly used to produce metastable alloys, the dopant profile becomes non-Gaussian(*9) and it becomes difficult to predict the effect of such bombardments. The control of the composition ratio of a binary alloy using high dosage ion implantation is limited to a very local range. Therefore, this technique is not adequate for producing an alloy with a uniform compositional ratio over a useful thickness.

In certain applications, the ion beam techniques have been recognized as an alternative method of growing thin and thick films. Depending on how the ion beam is involved in the film growth process, the technique can be considered to be subdivided into ion beam sputtering, ionized cluster beam deposition and ion beam deposition. The ion beam sputtering technique(*10,11,12) employs a high energy ion beam which is directed to the target; a substrate is situated close to the target so that the sputtered target material condenses on it efficiently. The substrate is usually maintained in high vacuum while the film is being grown and the risk of contamination is relatively low. This technique has an advantage of no restriction in the selection of film material to be deposited. Complications arise when the different sputtering coefficients have to be considered with different combinations of: target element, ion beam species, ion energy and ion incident angle. The energy of a sputtered particle ranges from a few tenths to a few tens eV. The film growth rate is high especially when a high current ion source is used but this technique lacks the precise control of film stoichiometry because it is difficult to control the direction and density of sputtered particles.

The ionized cluster ion beam technique(*13,14) employs a nozzle source from which a jet stream of multiatomic clusters is formed by the adiabatic expansion of vapor through the nozzle. Electron bombardment onto the jet stream causes partial ionization of the atomic clusters. Because of the small ratio of charge to number of atoms in a cluster, the average energy of individual atoms in the cluster is in the range of a few eV and it is dependent on the charge ratio and acceleration energy. This technique has the advantage of higher deposition rate compared with ion beam deposition. There are difficulties in maintaining a constant ratio of charge to cluster size and in controlling the amount of material deposited in a precise manner.

The direct deposition of a low energy ion beam onto a substrate has some distinctive features: namely the precise control of particle energy and of deposition density(*15-19). Because of the ion mass selection process, the ion beam deposited material maintains its high purity regardless of the impurity content in the source material. The disadvantages of this technique at present are a low film growth rate and a limitation on the selection of film materials which have to be ionized. To increase film growth rate a high current ion source is required but at high ion currents, ion optical aberrations and space charge expansion problems arise due to the low deposition energy.

To produce an alloy with a particular composition ratio, the most important consideration will be to control the introduction of each component of the alloy. The next important consideration will be to mix homogeneously over the whole volume. The controllability offered by the low energy ion beam deposition technique meets these alloy production requirements. The number of ions delivered to the substrate can be counted and when the desired ion dose is delivered the supply can be turned off instantly. Compared with sputtered particles or ionized clustered particles, the higher energy of ions is a favorable feature in the mixing process and the uniform, well-controlled energy of ions aids the uniformity of mixing. If a number of low energy ion beam sources with different ion species can be aligned to deposit their ions with low energy onto a common substrate, a new alloy can be formed in much the same fashion as in molecular beam epitaxy. The composition then, is directly related to the dose(or duty cycle) of each deposition species.

In this work, binary alloy film deposition using a sequential system with a single ion source will be proposed as an alternative to using a more expensive configuration of multiple beam lines(*20). Using a binary combination of Pb and Mg, a binary alloy with a preprogrammed composition ratio has been produced by such a sequential system. In this process, the sequence consists of depositing a very thin layer(a few tens of Å) of one element onto that of another(Figure 3-1).

The unit layer thickness is determined by the composition ratio of the desired alloy and the mixing range at the given ion beam energy. Usually the deposition energy is selected so that unity sticking coefficient is obtained with the selected energy (typically 50 eV). Under these conditions the composition ratio then becomes identical with the deposition dosage ratio of the different materials.

### B. Atomic mixing with low energy sequential ion beams

The atomic mixing processes under the bombardment of high energy ions are well understood and investigated by many researchers(*21-25). Initially the undesirable effects of atomic mixing were reported. For example, in the case of implantation doping, the broadening and shift of an existing dopant concentration profile is further modified if depth profiling is measured by a sputter-etching technique (*25,26,27). Later the advantageous side of atomic mixing was discussed and applied to produce metastable alloys using layered thin films and a high energy ion beam (*2-8,28-32).

The atomic mixing process can be described by Sigmund's transport equation(*23,33) :

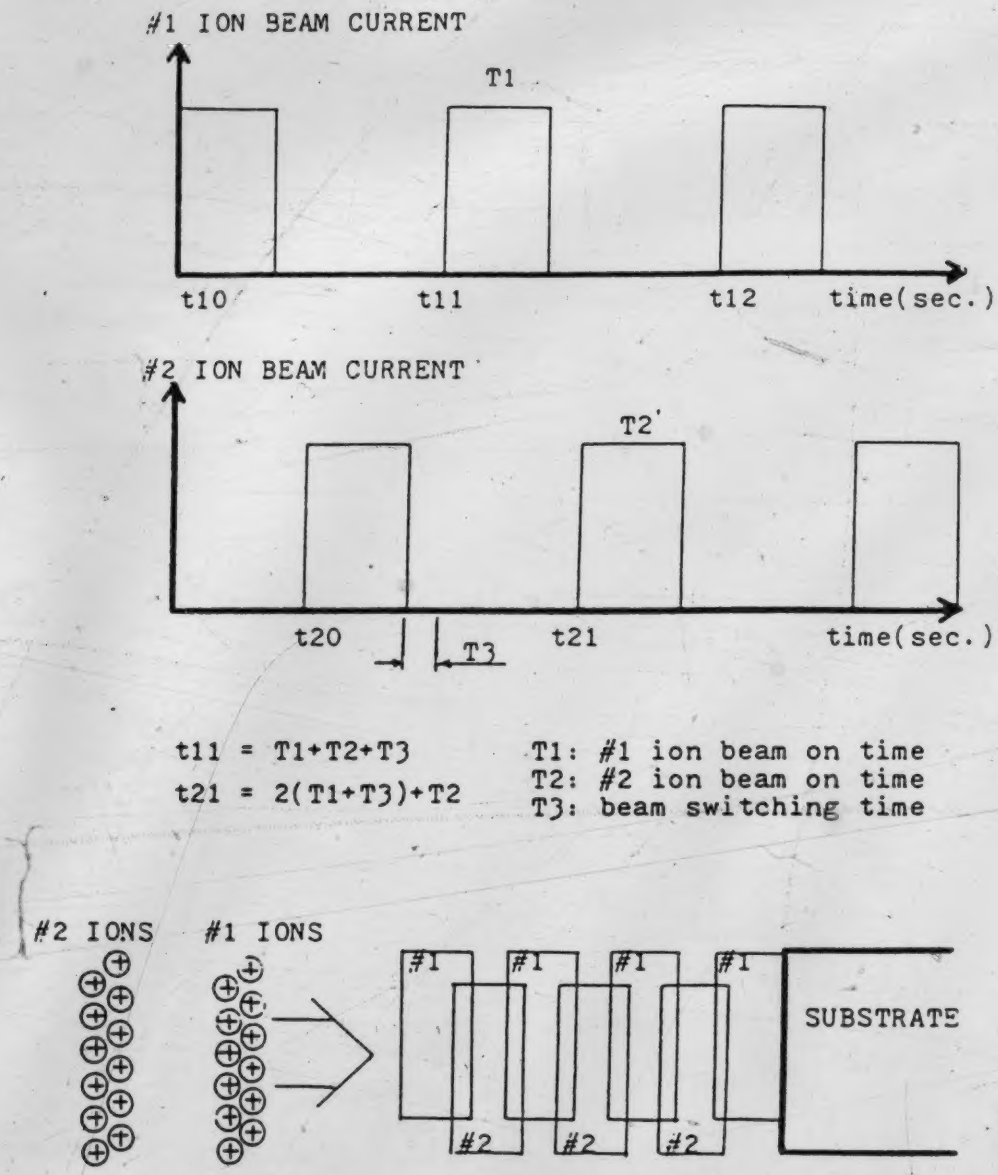

#1 ION BEAM CURRENT
T1
t10
t11
t12
time(sec.)
#2 ION BEAM CURRENT
T2
t20
T3
t21
time(sec.)
t11 = T1+T2+T3
t21 = 2(T1+T3)+T2
T1: #1 ion beam on time
T2: #2 ion beam on time
T3: beam switching time
#2 IONS
#1 IONS
#1
#1
#1
#1
#2
#2
#2
SUBSTRATE

Figure 3-1. The block diagram of sequential ion beam deposition.

$$\partial n(x)/\partial\phi=v\partial n(x)/\partial x+\int\{F'n(x-z)-F\,n(x)\}dz$$
$$+J^{-1}\,\partial/\partial x\{D\partial n(x)/\partial x\}+F_y(x)\ \text{---}\ (3\text{-}1)$$

where

$n(x)$ : atomic concentration at $x$

$v$ : surface erosion velocity by sputtering per unit ion current density

$F=F(x,z)$: relocation function, relocating from $x$ to $x+z$

$F'=F(x-z,z)$, relocating from $x-z$ to $x$

$z$ : relocation distance in the direction of $x$.

$J$ : ion current density

$D$ : diffusion coefficient

$F_y(x)$: normalized range distribution funtion

$\phi$ : ion fluence

The first term on the RHS of Sigmund's transport equation is for the sputtering effect, the second term for the atomic(ballistic) mixing, the third term for thermal diffusion and the fourth term for the primary injected particle resting after energy transfer.

Later, Carter and Collins proposed a diffusion approximation to the atomic mixing process using a diffusion coefficient and a drift velocity of the implanted and/or host species instead of Sigmund's relocation function. The Carter and Collins diffusion approximation formula for low-dose irradiation conditions can be described by(*34,35,36),

$\partial n(x)/\partial\phi = v\ J^{-1}\ \partial n(x)/\partial x - \partial/\partial x\{Vn(x)/J\} + \partial^2/\partial x^2\{Dn(x)/J\}$ --(3-2)

where

V : drift velocity of diffusion of injected species

With a high fluence of injected atoms in a local area, the local atomic concentration rises to saturation and any further injection of atoms to the area causes an outflow of excess atoms to an unsaturated region(*27,37). This outflow of atoms has been termed " collective current " by Collins. The diffusion approximation formula with collective current is given by(*27),

$J\ \partial n(x)/\partial\phi = v\ \partial n(x)/\partial x - \partial/\partial x(J_1 - J^s) + JF_y(x)$ ---------(3-3)

where

$J_1 = -\partial/\partial x\{D\ n(x)\} + V\ n(x)$ : injected current

$J^s$ : collective current

$F_y(x)$ : normalized range distribution

## C. Film growth using atomic mixing at and in surface layer

A new application of atomic mixing using low energy sequential ion beams is proposed here in producing metastable alloy films. In the present considerations, a low energy ion beam of 50 eV energy has a very short range which extends less than 10 Å(*17) into a solid target; the sputtering yield also is very small. The target surface then grows as the ions are delivered to the target surface. The ions also penetrate under the surface causing atomic mixing while the surface is growing. The Collins's collective current concept can be applied to this atomic mixing process caused by these short ranged low energy ions. A new term for surface growth now has to replace the surface erosion term in equation (3-3).

The average surface growth velocity, $v_0$ is given by,

$$v_0=J/n \text{ ------------------------- } (3\text{-}4)$$

where

n : alloy atomic concentration ( $cm^{-3}$)

The number of atomic displacements per incident ion with energy E is given by(*25),

$$n(E)=0.25E/E_{dmin.} \text{ --------------------- } (3\text{-}5)$$

where

$E_{dmin.}$ : minimum displacement energy

n(E) : number of displacement

E : initial ion energy

For Mg and Pb, the number of displacements by a 50 eV ion is about 1.25. Here $E_{dmin.}$(Mg)=10eV, and $E_{dmin.}$(Pb) =10.5eV(*25). Because of the low number of displacements per incident ion, the second term on the RHS of Sigmund's transport equation(Eq.3-1) becomes negligible everywhere except where an abrupt atomic concentration change is located. In other words, when considering the growth of an alloy film by the deposition of 50 eV ions, the major contribution to atomic mixing is from the location of incident ions embedded under the surface and collisional mixing processes can be neglected. The equation for the low energy ion beam deposition then can be given by,

$$\partial n(x)/\partial t=-v_0\partial n(x)/\partial x+JF_y(x)+\partial J^s/\partial x \text{ ------- } (3\text{-}6)$$

where

$v_0$: average film growth speed

$F_y(x)$ : normalized range distribution

$J^s$ : "collective current" due to the atomic concentration saturation

The atomic concentration of a binary alloy, $n(\alpha_1)$ is given by(*38),

$$n(\alpha_1)=N_2/(1+\beta\alpha_1) \text{ --------------- } (3\text{-}7)$$

where

$N_2$ : pure atomic concentration of species 2

$N_1$ : pure atomic concentration of species 1

$\alpha_1$ : composition ratio of species 1

$\beta=N_2/N_1 -1$

Other units used in the following equations are :

$n(x,t)$ : alloy atomic concentration at depth x and time t

$\alpha_i$ : species i composition ratio in an alloy.

$\alpha_i'$ : new composition ratio of species i after the introduction of an ion dose of $J\Delta t$.

$n_i$ : species i atomic concentration in an alloy.

$J_i$ : species i injected current density

$J_i^s$ : species i collective current density

$\Delta n_{i+}$ : species i atomic concentration increase.

$\Delta n_{i-}$ : species i atomic concentration decrease.

$\Delta n_{+}$ : total atomic concentration increase.

$\Delta n_{-}$ : total atomic concentration decrease.

$\Delta x$ : slab thickness

Figure 3-2 shows Pb/Mg binary alloy atomic concentration $n(\alpha_1)$ according to equation (3-7).

Even though the process has been modelled theoretically, the derivation of correct numerical values for the parameters in atomic mixing is not a simple matter at all. Sometimes a numerical method is convenient for solving such a process.

To derive the alloy composition from equations (3-6) and (3-7) numerically, it is desirable to rewrite equation (3-6) into a different format which can be machine implemented with ease. While ions are being deposited into the film surface, the alloy composition and atomic concentration at depth x below the surface is a function of time, t ( when x is less than the maximum range of incident ions) if we assume negligible collisional mixing with 50 eV ions. Beyond the depth of the maximum range of 50 eV ions from the surface, the alloy composition is assumed not to change any further by the action of injected ions.

For modelling purposes, the alloy film is assumed to be a collection of thin slabs with slab thickness of $\Delta x$. It is

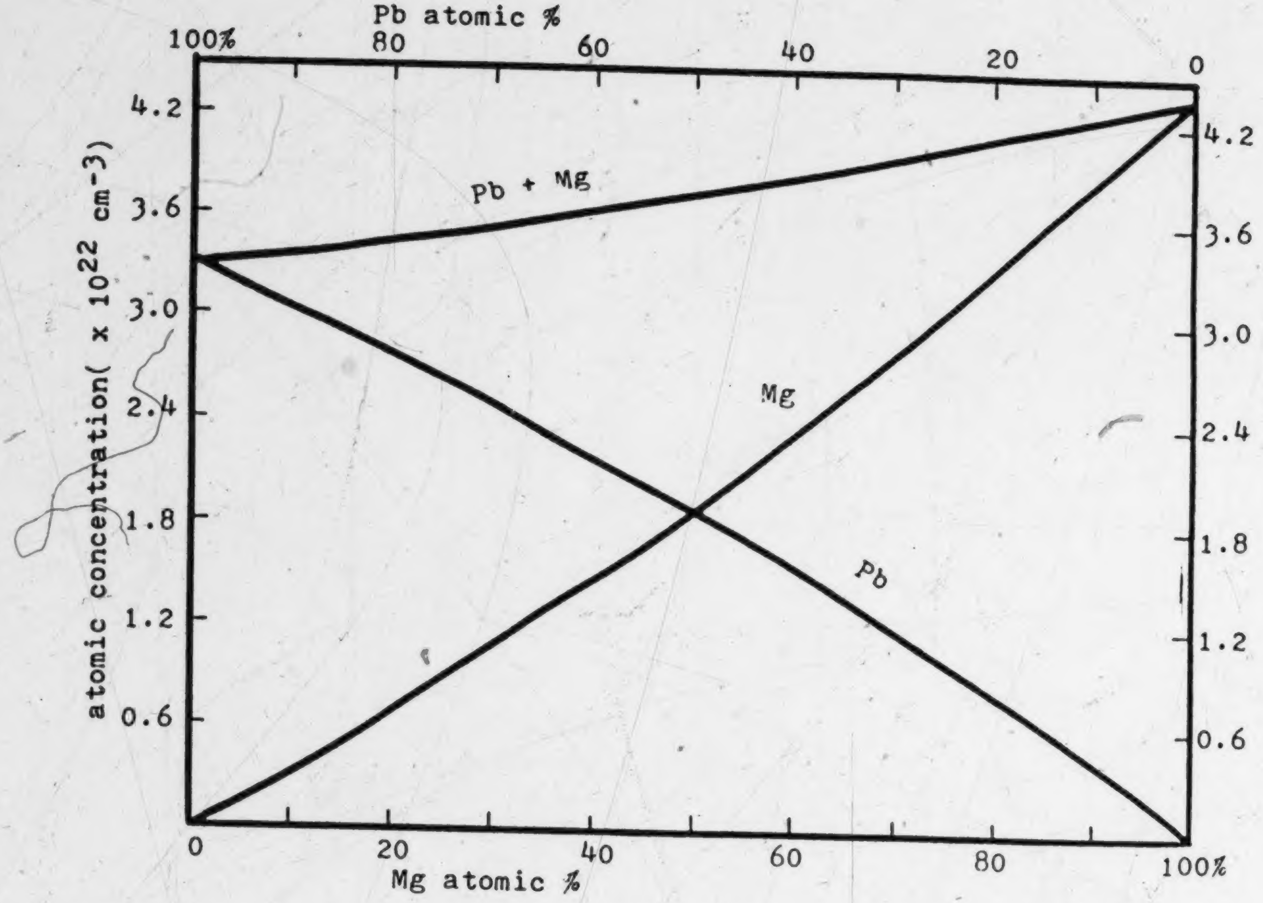


Figure 3-2. Pb/Mg binary alloy atomic concentration diagram.

also assumed that each slab is saturated except for the incomplete surface slab and furthermore, that the alloy composition is homogeneous in each slab. Due to the discrete increment of film thickness used in the calculation, film thickness x is considered independent of time t while a new surface slab is being grown.

Then equation (3-6) without the surface growth term is valid between new surface completions and it becomes,

$$n(x,t1)-n(x,t2)=JF_{y}(x)\Delta t+\Delta t\ \partial J'/\partial x \text{ ----------- } (3\text{-}8)$$

where

$\Delta t=t2-t1 < t_s$

$t_s$ : time required to complete a new surface slab

$\Delta t$ has to be chosen to be less than the surface increment time $t_s$ so that the time independence of depth x is maintained for a number of ion injection cycles. The first term in the RHS of equation (3-8) can be easily implemented using published ion range distribution function data $F_y(x)$ and ion beam current density J.

The second term for the Collins "collective current" due to alloy concentration saturation is given by(*27),

$$J'_1=\gamma_1 n_1[(1+\beta)J_1+J_2]\ [\gamma_1 n_1(1+\beta)+\gamma_2 n_2]^{-1} \text{ ------- } (3\text{-}9)$$

where

$\gamma_i$ : mobility of species i

With the assumption of identical mobility of species 1 and 2 in the collective current, then from equation (3-7) and

(3-9), the collective current with new composition $\alpha'_1$ after injection of $J_1$ and $J_2$ becomes,

$$J'_1=\alpha'_1(N_2J_1+N_1J_2)[\alpha'_1N_2+(1-\alpha'_1)N_1]^{-1}$$

and

$$J'_2=(N_1J_2+N_2J_1)(1-\alpha'_1)[\alpha'_1N_2+(1-\alpha'_1)N_1]^{-1}$$

The total collective current is,

$$\begin{aligned}J'&=J'_1+J'_2\\&=[N_1J_2+N_2J_1][\alpha'_1N_2+(1-\alpha'_1)N_1]^{-1}\ \text{-------}\ (3\text{-}10)\end{aligned}$$

The atomic concentration increase $\Delta n_+$ due to the injected current in the m th slab with slab thickness of $\Delta x$ is,

$$\begin{aligned}\Delta n_+&=\Delta n_{1+}+\Delta n_{2+}\\&=(J_1+J_2)\Delta tF_y(m)/\Delta x\ \text{---------------}\ (3\text{-}11)\end{aligned}$$

The concentration decrease $\Delta n_-$ due to the collective current is,

$$\Delta n_-=(J'_1+J'_2)\Delta t\ F_y(m)/\Delta x\ \text{---------------}\ (3\text{-}12)$$

From equation (3-10) and (3-12), equation (3-12) becomes,

$$\Delta n_-=(N_1\Delta n_{2+}+N_2\Delta n_{1+})[\alpha'_1(N_2-N_1)+N_1]^{-1}\ \text{-------}\ (3\text{-}13)$$

The new alloy atomic concentration $n(\alpha'_1)$ after injection is,

$$n(\alpha'_1)=n(\alpha_1)+\Delta n_+-\Delta n_-\ \text{-----------}\ (3\text{-}14)$$

After incorporating equations (3-7), (3-12) and (3-13) into (3-14), new composition of species 1, $\alpha'_1$ becomes,

$$\alpha'_1=\{\alpha_1 N_1 N_2+\Delta n_{1+}[\alpha_1(N_2-N_1)+N_1]\}\{(\Delta n_{1+}+\Delta n_{2+})[\alpha_1(N_2-N_1)]+N_1 N_2\}^{-1} \text{ ---------------(3-15)}$$

Equations (3-12),(3-13) and (3-15) are now readily implementable. The concentration increase due to the injected current is calculated from equation (3-12) using the known ion beam current density and published ion range distribution data. A new composition after injection which is followed by an outflow of excess atoms is given by equation (3-15).

Because the excess atoms removed from one slab become the injected atoms to the next slab, a new composition calculation continues until the excess atoms sink into the unsaturated surface slab. The ion range distribution function data $F_\gamma(m)$ used in this computer simulation is taken from the range data of 50 eV $Ge^+$ into a polycrystalline Ge target reported by Thomas et. al(*17), using computer simulation with the MARLOWE model (Figure 3-3).

All of the Pb/Mg alloy deposition simulations depicted in Figure 3-4(a-d) started with a 10 Å thick Mg film as a substrate. The results demonstrate the possibility of being able to control the alloy composition ratio without restriction over the thickness of the film because the film grows as the material is deposited and mixed . The most sensitive parameter governing the homogeniety of alloy composition with this technique is the selection of an ion flux for each ion beam in the sequential deposition batch.

For example, an ion fluence of about $6 \times 10^{13}$ ($cm^{-2}$) or less gives excellent homogeniety while $3 \times 10^{14}$ ($cm^{-2}$) gives fluctuation of composition ratio between sequences.(Figure 3-4a-d)

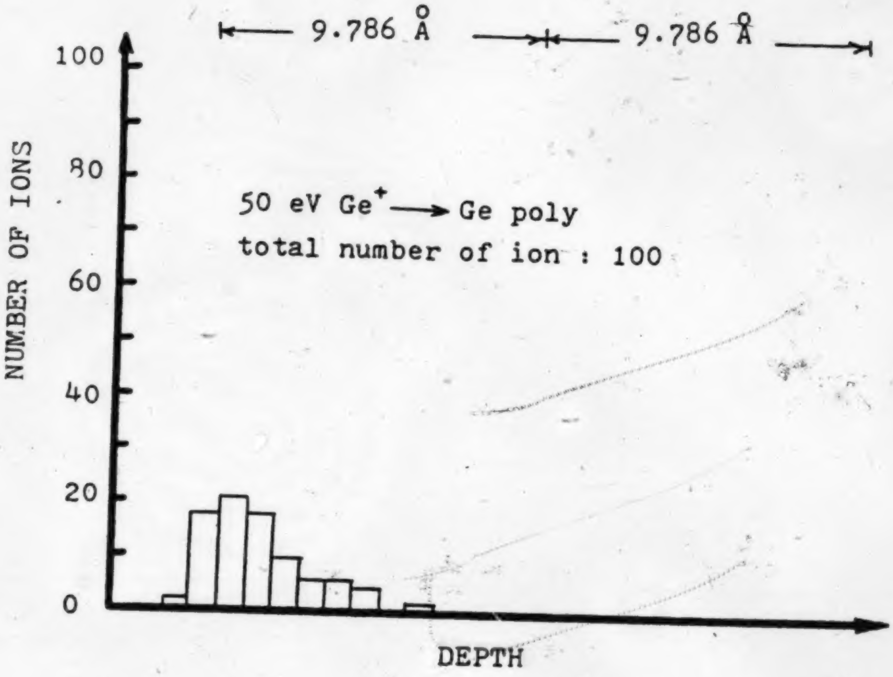


Figure 3-3. Ion range diagram of 50 eV Ge⁺ onto poly Ge.(from Thomas et. al,*17)

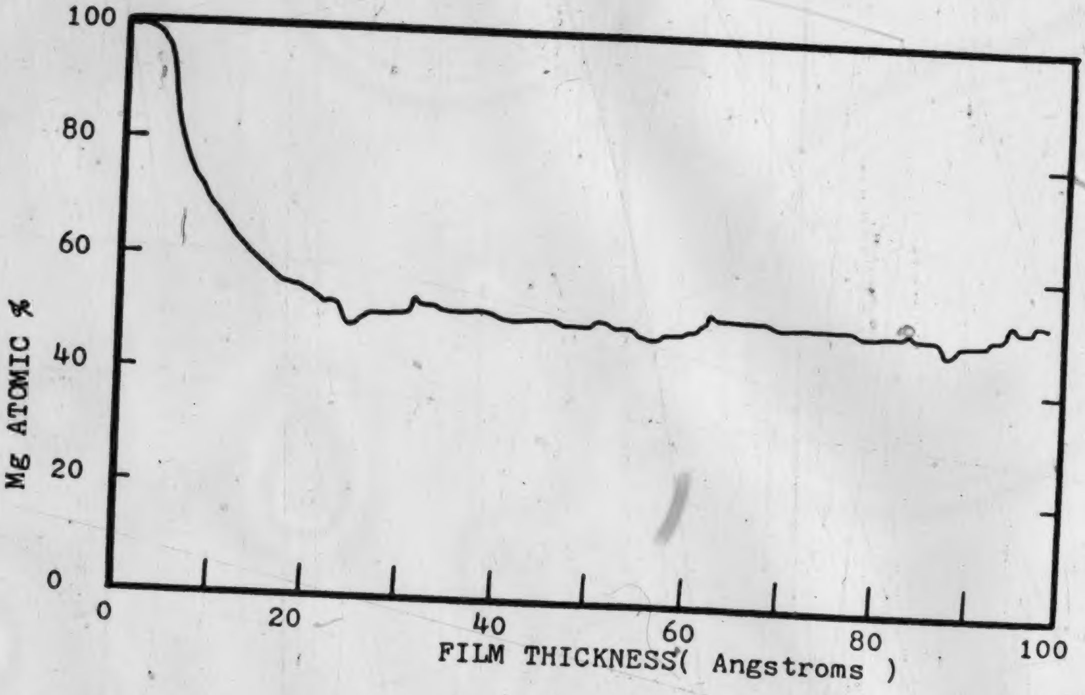


Figure 3-4a. Pb/Mg binary alloy composition spectrum-1
( Ion beam current(Pb/Mg):10/10 uA, batch time: 1/1 sec.)

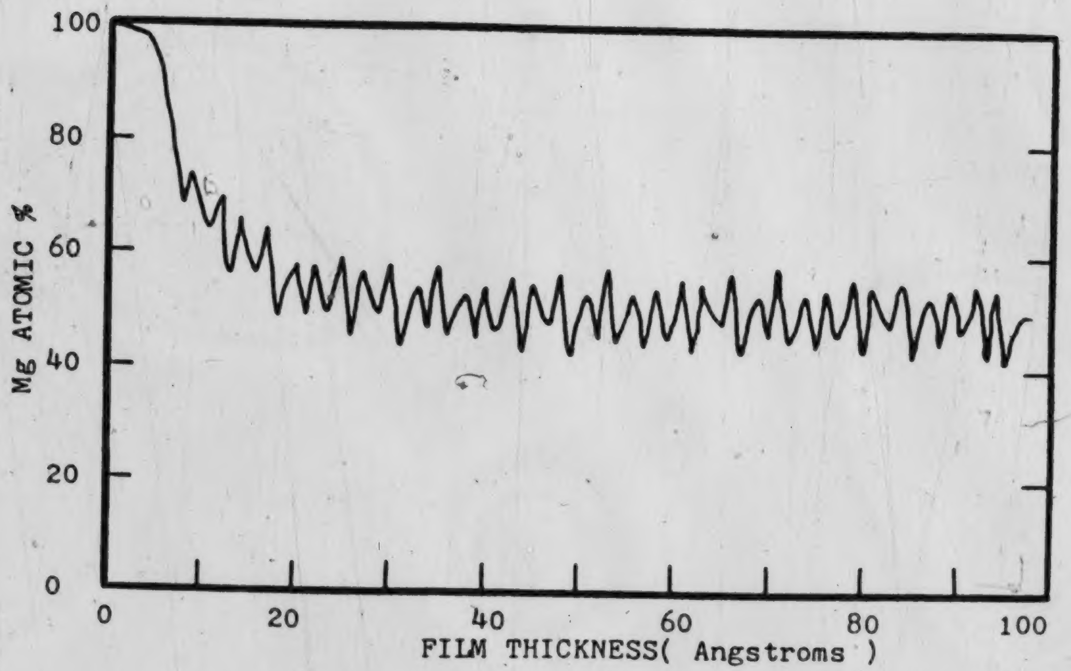


Figure 3-4b. Pb/Mg binary alloy composition spectrum-2
( Ion beam current(Pb/Mg):10/10 uA, batch time: 5/5 sec.)

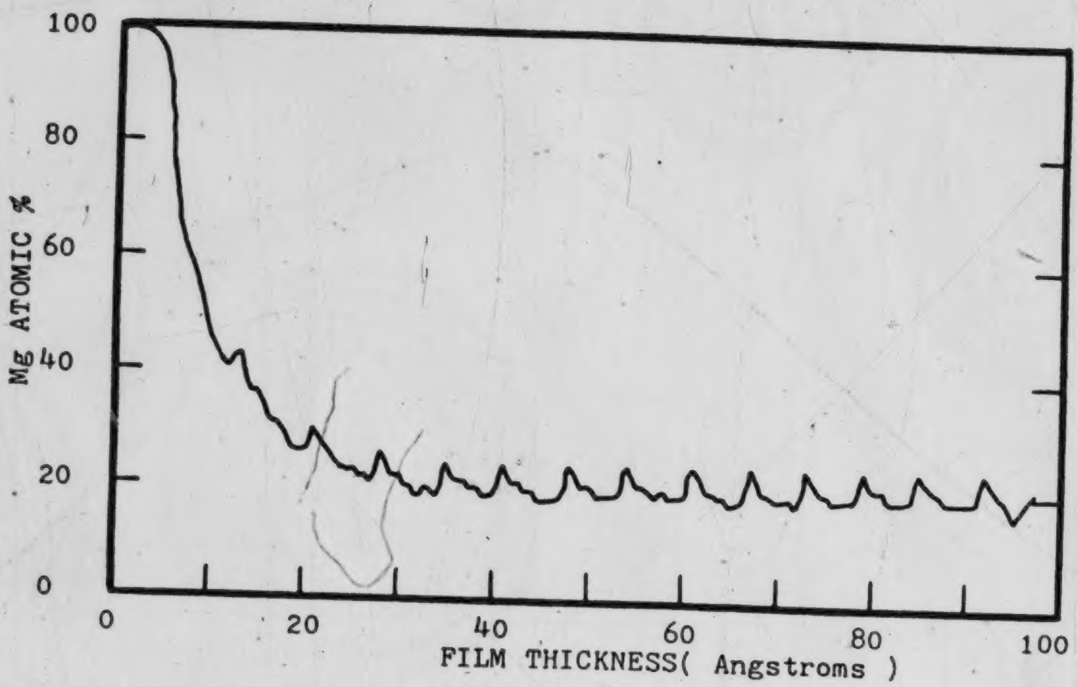


Figure 3-4c. Pb/Mg binary alloy composition spectrum-3
( Ion beam current(Pb/Mg):10/10 uA, batch time: 1/4 sec.)

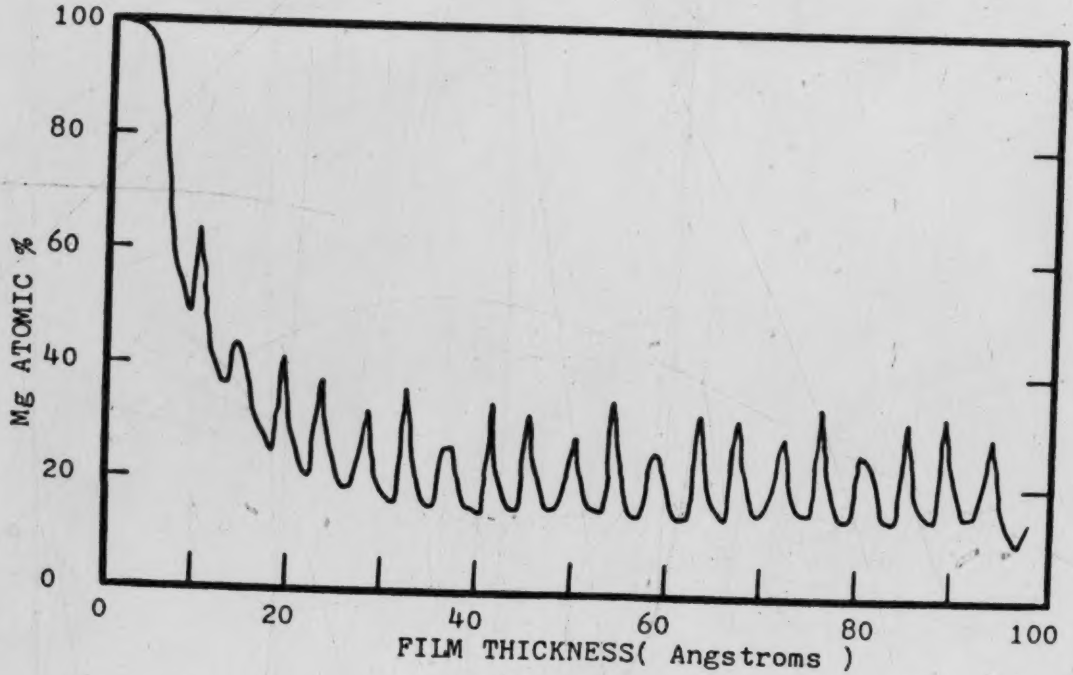


Figure 3-4d. Pb/Mg binary alloy composition spectrum-4

(Ion beam current(Pb/Mg):10/10 μA, batch time: 5/20 sec.)

# IV. Hot Cathode Electron Impact Ion Source

## A. Introduction

The ion source is the most important single element in the ion beam system. The basic capabilities and limitations of an ion beam system are mainly dependent on the capability of the ion source itself. The characteristics of the ion source determine the film quality as well as production yield. The ion source used in this experiment was originally designed by Colutron and it was modified to accomodate higher temperature source material by Amano(*1). It has been modified further in the present work to handle two different materials simultaneously. It is equipped with two separate furnaces connected in series. The furnace next to the discharge chamber is for high melting temperature elements and the rear end one is for lower melting temperature elements(Figure 4-1).

The ionization of gas or vapor molecules by energetic electrons is one of the most common techniques used to produce ion beams of various elements. Primary electrons emitted from a thermionic cathode initiate the ionization by colliding with gas molecules in the discharge chamber. The secondary electrons produced by the collisions between the primaries and the gas molecules have kinetic energy equivalent to the difference between the primary electron energy and the ionization energy of molecules. A fraction of the secondary electrons have enough energy to ionize more

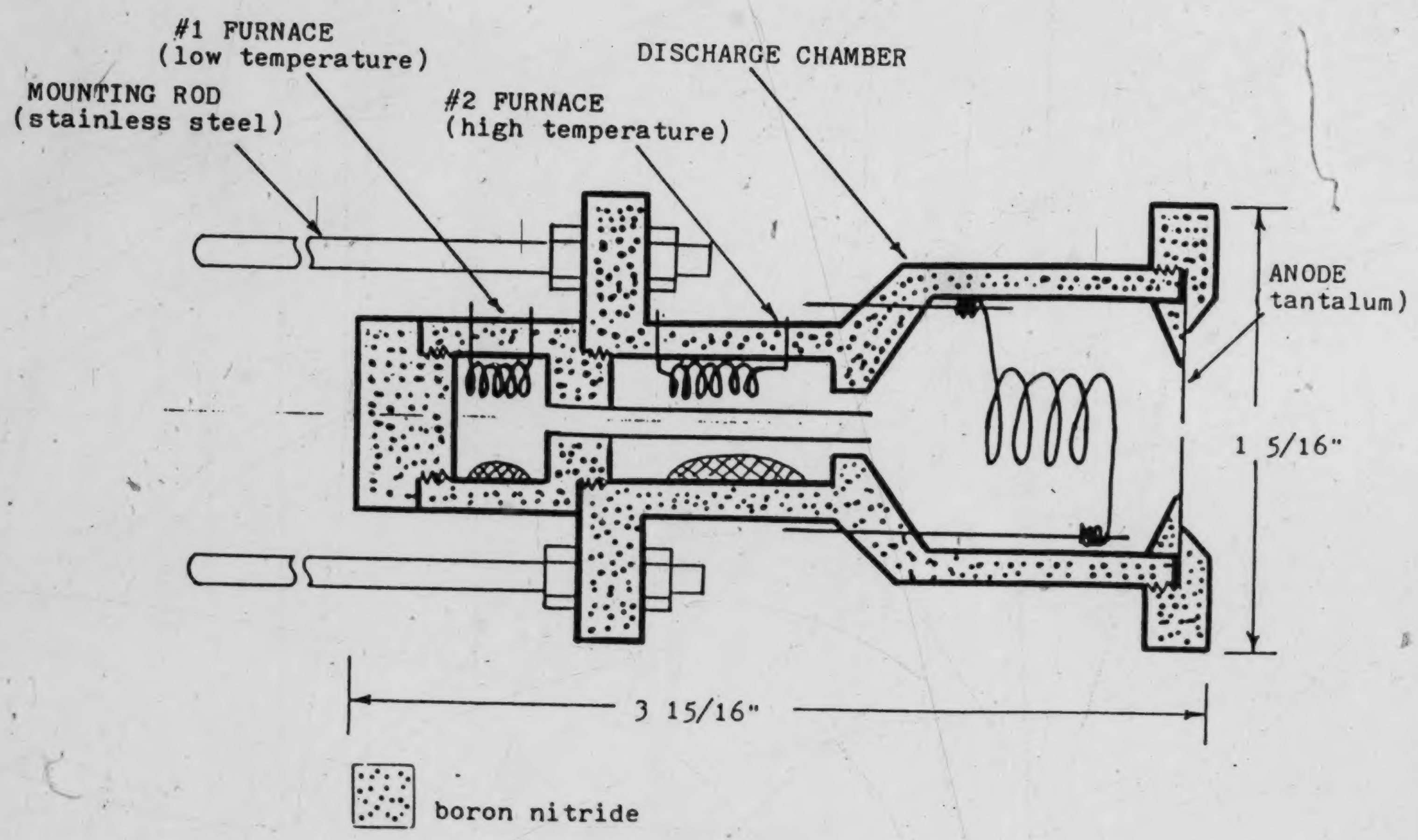

#1 FURNACE
(low temperature)
MOUNTING ROD
(stainless steel)
#2 FURNACE
(high temperature)
DISCHARGE CHAMBER
ANODE
tantalum)
1 5/16"
3 15/16"
boron nitride

Figure 4-1. Ion source with two serial furnaces.

molecules. The ions produced in this process are accelerated towards the cathode by the electric field existing between cathode and anode. More electrons are emitted from the cathode by these bombarding ions. This electron multiplication process continues until equilibrium is reached, i.e. the space charge limited electron current from the cathode produces ions equivalent to the sum of the ion loss caused by ion flow to the cathode, to recombination along the source wall and to ion extraction through the ion beam system.

A brief review of the physical operation of a typical gas discharge ion source is presented here. A study of the effect of the source parameters is undertaken with a view to optimising the operation of the source used in this work.

The symbols used in equations in this Chapter are summarized as;

$J^+$ : ion current density
$J^-$ : electron current density
$I^+$ : ion current
$I^-$ : electron current
$I_d$ : source discharge current($=I^+ + I^-$)
$I_x^+$ : ion current extracted from ion source
$\rho^+$ : ion space charge density
$\rho^-$ : electron space charge density
$\rho_t^+$ : thermal ion space charge density
$\rho_t^-$ : thermal electron space charge density
m : electron mass

$M$ : ion mass

$N^+$ : ion density

$N^-$ : electron density

$V_d$ : ion source discharge potential(anode potential)

$V_s$ : cathode sheath potential

$V_y$ : source wall potential

$V_t^+$ : potential of thermal ions(=$kT^+/e$)

$V_t^-$ : potential of thermal electrons(=$kT^-/e$)

$v^+$ : ion velocity

$v^-$ : electron velocity

$v_t^+$ : thermal ion velocity

$v_t^-$ : thermal electron velocity

$v_d^-$ : electron diffusion velocity

$T^+$ : ion temperature

$T^-$ : electron temperature

$e$ : electronic charge

$k$ : Boltzman's constant

$p$ : source discharge pressure

$l$ : plasma length

$S_i$ : electron ionization coefficient

## B. Ion source operational parameters analysis

The electron impact ion source used in the ion beam deposition system has been analyzed in terms of actual operating parameters such as discharge current, discharge voltage and source pressure. The analysis of the cathode sheath region in an arc discharge has been reported by

Langmuir(*2), Crawford and Cannara(*3), and Prewett and Allen(*4). In the next sections, these earlier studies will be applied to electron impact ion source analysis. An electron impact ion source can be divided into two basic regions inside the ion source when the discharge is turned on. They are the cathode sheath region and the plasma region(Figure 4-2). The cathode sheath region is formed in front of the cathode with a space charge limited flow mainly of electrons. In the cathode sheath region the electric field is maximum near the center of the sheath(*7). The plasma region forms between the cathode sheath and the anode. The total charge in the plasma region is considered zero and thus the field is negligible. Therefore almost all of the discharge potential drop is applied across the cathode sheath.

### C. The effect of ion source operational parameters on the cathode sheath thickness

The thickness of the cathode sheath changes the length of the plasma in the ion source especially when the sheath thickness is comparable with the cathode to anode gap. The longer the cathode sheath is, the shorter the plasma length becomes. Before deriving the plasma density in an ion source, the cathode sheath thickness has to be defined. For the simplicity of the analysis, the following assumptions are made.

- A set of parallel plate anode and cathode.

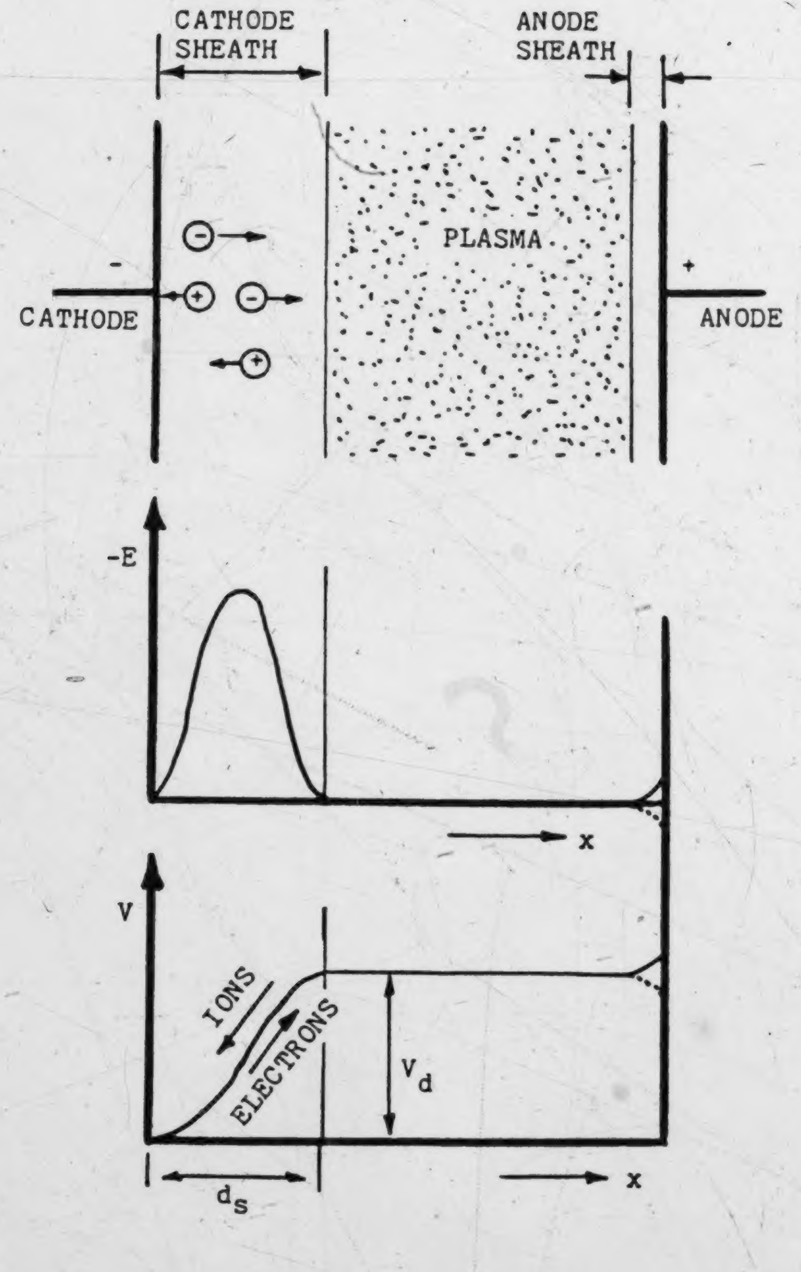

CATHODE
SHEATH
ANODE
SHEATH
PLASMA
-
+
CATHODE
ANODE
-E
x
V
IONS
ELECTRONS
$V_d$
$d_s$
x

Figure 4-2 Potential and field diagram of hot cathode electron(*7) impact ion source

- The potential drop across the cathode sheath is equivalent to the discharge potential. (no field in the plasma, and a negligible potential drop across the anode sheath)
- The energy of thermal electrons from the plasma is negligible compared with the discharge potential. None of these electrons reaches the cathode.
- The thermal electron energy distribution is considered to follow Boltzman's law
- There are no collisions between ions and electrons in the cathode sheath region.
- The electron flow from the cathode is space charge limited.

Figure 4-3 shows the charge flow between cathode and anode in the ion source. The electron space charge density $\rho^-$ in the cathode sheath with potential $V_s$, is given by,

$$\rho^- = J^-/v^- = J^-[m/(2eV_s)]^{1/2} \text{ ------------- } (4\text{-}1)$$

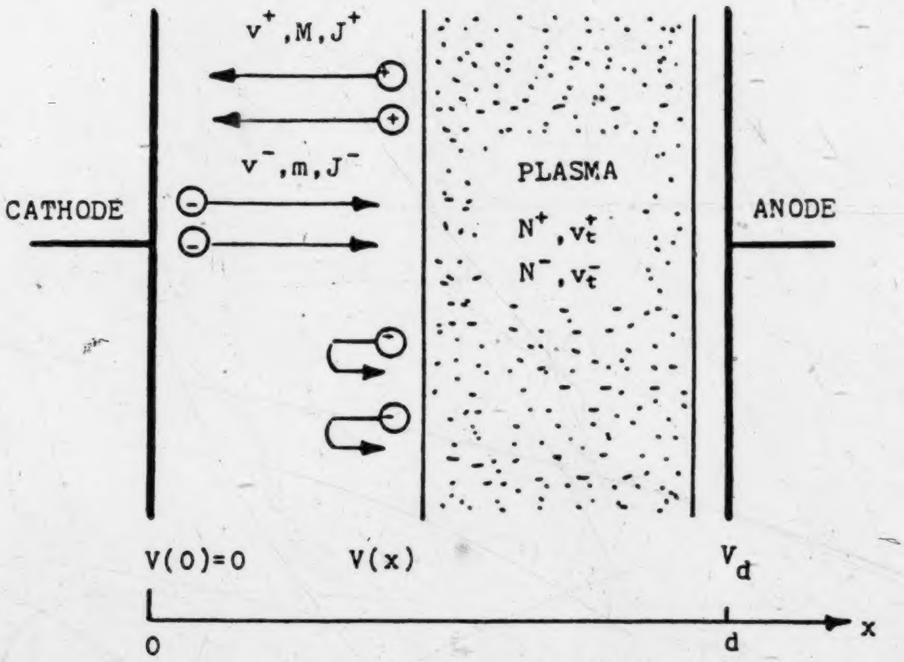
The velocity of ions, $v^+$ moving into the cathode sheath with an equivalent thermal potential of $V_i^+$ is given by,

$$v^+ = \{2e(V_d + V_i^+ - V_s)/M\}^{1/2} \text{ --------------- } (4\text{-}2)$$

The ion space charge density, $\rho^+$ in the cathode sheath is given by,

$$\rho^+ = J^+/v^+ = J^+\{M/[2e(V_d + V_i^+ - V_s)]\}^{1/2} \text{ ------- } (4\text{-}3)$$

The space charge density, $\rho_i^-$ of thermal electrons moving


$v^+$,M,$J^+$
$v^-$,m,$J^-$
CATHODE
PLASMA
$N^+$,$v_t^+$
$N^-$,$v_t^-$
ANODE
V(0)=0
V(x)
$V_d$
0
d
x

$v^+$, $v^-$ : velocity, ion, electron ( m/sec)
$J^+$, $J^-$ : current density, ion, electron ( amp./m$^2$)
M , m : mass, ion, electron (Kg)
$N^+$,$N^-$ : ion, electron density ( m$^{-3}$)
$v_t^+$ : ion thermal velocity (m/sec)
$v_t^-$ : electron thermal velocity (m/sec)

Figure 4-3: Charge flow between cathode and anode.

into the cathode sheath region with an equivalent thermal potential of $V_t$ is given by,

$$\rho_t=eN^- \exp\{-(V_d-V_s)/V_t\} \text{ --------------(4-4)}$$

The total charge density in the cathode sheath, $\rho$ is given by

$$\rho = \rho^+ - \rho^- - \rho_t \text{ -------------------(4-5)}$$

According to the Poisson's equation,

$$d^2V/dx^2 = -\rho/\epsilon_0 \text{ ----------------- (4-6)}$$

Using equation 4-1,4-3, 4-4 and 4-5 , equation 4-6 can be re-written as,

$$d^2V/dx^2= \epsilon_0^{-1}\{J^-[m/(2eV_s)]^{1/2}-J^+\{M/[2e(V_d+V_t-V_s)]\}^{1/2}+$$
$$eN^- \exp[-(V_d-V_s)/V_t]\} \text{ --------- (4-7)}$$

After integrating equation 4-7 and applying boundary conditions: $dV/dx=0$, at $V_s=0$ and $V_s=V_d$, i.e. no field exists at the cathode surface and the cathode sheath boundary, the electron and ion current density is given by,

$$J^-= J^+(M/m)^{1/2}\{(1+V_t/V_d)^{1/2}-(V_t/V_d)^{1/2}\}-$$
$$0.5eN^-V_t[2e/(mV_d)]^{1/2}\{1-\exp(-V_d/V_t)\} \text{ ----- (4-8)}$$

The ion source discharge current, $I_d$ monitored with a current meter is the total combined sum of electron current $I^-$, and ion current $I^+$. The thermal electron flow initiated from the plasma towards the cathode is not included in the monitored discharge current because the thermal electron energy is not high enough to overcome the discharge potential across the cathode sheath and it is reflected back to the plasma after spending all its kinetic energy in the retarding field of the cathode sheath region. Using the monitored total discharge current density J, equation 4-8 can be re-defined to the ratio of electron and ion current density.

$$J^-/J^+= A/B \text{ ------------------------ } (4\text{-}9)$$

where

$$A=\{J(M/m)^{1/2}[(1+V_t^+/V_d)^{1/2}-(V_t^+/V_d)^{1/2}]-$$

$$eN^-V_t^-[e/(2mV_d)]^{1/2}[1-\exp(-V_d/V_t^-]\}$$

$$B=\{J+eN^-V_t^-[e/(2mV_d)][1-\exp(-V_d/V_t^-)]\}$$

If $V_t^+ \cong 0$ and $V_t^- \cong 0$, i.e. the initial energy of both thermal electrons and ions is negligible, then the ratio of electron and ion current is given by,

$$I^- /I^+ = (M/m)^{1/2} \text{ ------------------- } (4\text{-}10)$$

Equation 4-10 is the absolute upper limit of the electron and ion current ratio in the cathode sheath region. Using equation 4-7 and the boundary condition of no field at cathode and sheath boundary, a first order differential equation is given by,

$$dV/dx=0.5\epsilon^{1/2} \{J^-[mV_s/(2e)]^{1/2}+J^+[M/(2e)]^{1/2}[(V_d+V_t^+-V_s)^{1/2}-(V_d+V_t^+)^{1/2}]+0.5eN^-V_t^-\exp(1-V_s/V_d)\}^{-1/2} \text{ --} (4\text{-}11)$$

Before the ion source plasma density is calculated, the cathode sheath thickness change caused by operational parameters has to be estimated because the thicker the sheath is, the less the plasma volume becomes. In reality, most of the ion source operational parameters are related to each other and hardly any single parameter is completely independent. It is instructive to have a view of the effect on the cathode sheath thickness, over a single parameter change under the assumption of independence of each of the operational parameters. The following physical dimensions and operating parameters have been used in the next numerical calculations.

a. cathode area(a) : 1 $cm^2$
b. discharge potential($V_d$) : 100 volts
c. discharge current($I_d$) : 600 ma
d. thermal electron energy($V_i^-$) : 2.0 eV
e. ion initial energy($V_i^+$) : 0.3 eV
f. plasma density($N^+$) : 1 x $10^{16} m^{-3}$
g. gas species(M) : $N_2$
h. ion/electron mass sq. root ratio $(M/m)^{1/2}$ : 160

The cathode sheath thickness is given as the function of the following parameters:

- Discharge potential($V_d$)

  50 volts : 0.39 mm, 100 volt : 0.66 mm, 150 volt : 0.9 mm
- Discharge current($I_d$)

  300 ma : 0.94 mm, 600 ma : 0.66 mm, 1000 ma : 0.51 mm
- Thermal electron energies($V_i^-$)

2 eV : 0.66 mm, 3 eV : 0.66 mm

- Ion initial energies($V_i$)

  0.1 eV : 0.66 mm, 0.3 eV : 0.66 mm, 0.5 eV : 0.66 mm

- Ion species(M)

  $N_2$(14) : 0.66 mm, Mg (24) : 0.65 mm, Ti (48) : 0.64 mm, Ag (107) : 0.63 mm, Pb (208) : 0.63 mm

- Plasma density($N^+$($m^{-3}$))

  $1 \times 10^{15}$ : 0.66 mm, $1 \times 10^{16}$ : 0.66 mm, $1 \times 10^{17}$ : 0.67 mm, $5 \times 10^{17}$ : 0.69 mm, $1 \times 10^{18}$ : 0.74 mm

The most sensitive parameter on the cathode sheath thickness is discharge current. The sheath thickness change is less than 5 % of the distance between anode and cathode with the extreme change of the most sensitive parameter. Therefore the plasma volume used in the next section will be treated as a constant under normal operating conditions. The ratio of electron and ion current in the cathode sheath region remains about 90 - 95 % of the upper limit,i.e. the square root of the mass ratio of ion and electron. This ratio starts falling drastically when plasma density is increased over $1 \times 10^{17}$($m^{-3}$). When the plasma can supply a comparative quantity of ions, the electron flow from the cathode becomes reduced in proportion to the ion flow from the plasma.

### D. The maintenance of high plasma density

An ion source with high plasma density in the discharge chamber can supply high density ion current through an extractor. Because of the fluid-like behavior of the plasma surface(where ions are extracted) a high density plasma can supply higher ion current while maintaining the space-charge-limited current which equals the ion supply from the plasma. In this section we will look into conditions which give the maximum plasma density in the discharge chamber. When the plasma in the ion source is stabilized, the ion production and loss are considered balanced. Whenever this balance is broken for any reason, a new balancing point is attempted and will be established unless the ion production rate is less than the critical level. The ion production rate, $dn_1^+/dt$ is given by(*5),

$$dn_1^+/dt = \beta I^- /e \text{ (ion pairs/sec) ------(4-12)}$$

where

$\beta = S_i\, p\, l$ (ion pairs/electron) : electron ionization factor

Ion loss is caused by (a) the ion current flow to the cathode from the plasma, (b) extracted ion current through the ion extraction electrode, and (c) the ion loss due to recombination along the source wall.

When $I^-$ and $I^+$ are defined as electron and ion current between cathode and plasma, and $I_x^+$ as the extracted ion current into the ion beam system from the ion source, then the ion loss rate, $dn_2^+/dt$ due to the ion current flow to the cathode is given by,

$$dn_2^+/dt = I^+/e \text{ (ions/sec) } \text{-------} \ (4\text{-}13)$$

and the ion loss rate, $dn_4^+/dt$ due to the ion extraction is given by,

$$dn_4^+/dt = I_x^+/e \text{ -----------------------} (4\text{-}14)$$

The electrons and ions recombine at the insulated source wall which is regarded as an insulated ion probe in the plasma where both particle current densities are equal in magnitude. The electron diffusion current in the plasma is considerably larger than the ion diffusion current density because the electron temperature is larger than the ion temperature in the plasma. At the surrounding insulated source wall surface, the electron and ion current density must have equal magnitude to achieve equilibrium. To meet this condition, the wall becomes negatively charged developing a potential $V_y$. The ion loss rate, $dn_3^+$ due to the source wall recombination is given by(*6),

$$dn_3^+/dt = N^+ v_d^- w \exp[-eV_y/(kT^-)] \text{ -------} \ (4\text{-}15)$$

where

$v_d^-$ ; electron diffusion velocity$(=[kT^-/(2\pi m)]^{1/2})$

$V_y$ ; wall potential$(=(kT^-/e)\ln[8M/(\pi m)]^{1/2})$

w : source wall area

This loss becomes very significant when the ion source is operating at high plasma density. Therefore the discharge chamber has to be shaped to minimize the source wall area to reduce ion loss along the wall. This condition contradicts the anode and cathode electrode geometry which must have a certain surface area to meet the discharge current requirements. If the discharge current requirements can be satisfied with a minimum surface area of cathode, anode and source walls then it follows that the ion loss due to recombination along the source wall will be a minimum. If we balance ion production and ion loss, then from 4-12,4-13,4-14 and 4-15 :

$$\beta I^-/e=(I^+ + I_x^+)/e + N^+ w\ v_d^- \exp[-eV_y/(kT^-)] \text{ --------} (4\text{-}16)$$

$$N^+=(\beta I^- - I^+ - I_x^+)\ \{ewv_d^- \exp[-eV_y/(kT^-)]\}^{-1} \text{ ----} \ (4\text{-}17)$$

From eq. 4-9 and 4-17, the plasma density $N^+$ is given by,

$$N^+= A/B \text{ -----------------------} (4\text{-}18)$$

where

$A=I_d\{\beta(M/m)^{1/2}[(1+V_t^+/V_d)^{1/2}-(V_t^+/V_d)^{1/2})]-1\}-$

$I_x^+\{1+(M/m)^{1/2}[(1+V_t^+/V_d)^{1/2}-(V_t^+/V_d)^{1/2}]\}$

$B=C\{1+(M/m)^{1/2}[(1+V_t^+/V_d)^{1/2}-(V_t^+/V_d)^{1/2}]\}+$

$aV_t^- e[e/(2mV_d)]^{1/2}[1-\exp(-V_d/V_t^-)](1+\beta)$

$C=ewV_d^- \exp[-eV_y/(kT^-)]$

a ; cathode area

If we approximate equation 4-18, using $V_t^+ << V_d$ , $V_t^- << V_d$ and $1 << (M/m)^{1/2}$, then eq. 4-18 becomes,

$N^+=D/E$ ---------------------- (4-19)

where

$D=I_d[\beta(M/m)^{1/2}-1]-I_x^+[1+(M/m)^{1/2}]$

$E=C[1+(M/m)^{1/2}]+aV_i^- e[e/(2mV_d)]^{1/2}(1+\beta)$

Differentiating equation 4-19 with $\beta$,

$dN^+/d\beta > 0$ --------------------------------(4-20)

The electron ionization factor, $\beta$ is determined by the plasma length l, electron ionization cefficient $S_i$ and source pressure p(Equation 4-12). The plasma length is considered constant when the physical gap between anode and cathode is much larger than cathode sheath thickness. The electron ionization coefficient, $S_i$ is dependent on electron energy. The electron energy in an ion source discharge is dependent on discharge pressure when the ion source is operated under constant discharge current mode. Therefore under constant discharge current mode operation, the source pressure is the only input parameter which controls the ionization factor, $\beta$. The maximization of $\beta$ can be achieved by adjusting the source pressure. From equation 4-19, it is necessary to maintain $\beta$ at maximum to keep the plasma density $N^+$ at a maximum.

The electron ionization coefficient $S_i$ peaks when anode potential $V_d$ is between 80 and 120 eV for the majority of gases with the exception of the alkali vapors which peak at between 15 and 30 eV(*5)(Figure 4-4). If the characteristic curve of discharge potential vs. discharge pressure under constant discharge current is known, then we can draw a new characteristic curve of $\beta$ vs. discharge pressure. The peak of $\beta$ will be obtained at or near the discharge pressure where the discharge potential has the maximum $S_i$. The discharge pressure with peak $\beta$ becomes the optimum pressure and under these conditions the highest plasma density ~~in~~ the ion source is obtained under the conditions of a constant discharge current. The optimum pressure can be determined experimentally by monitoring ion current as source pressure is slowly varied. The optimum pressure also differs when ion species, source geometry or discharge current is changed.

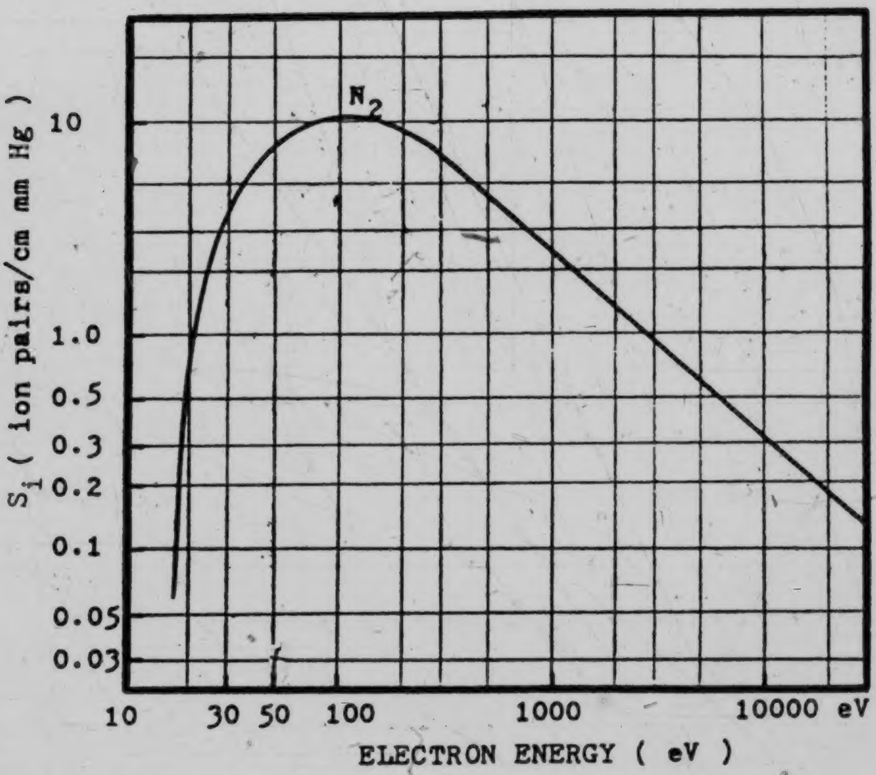


Figure 4-4 : Electron ionization coefficient of $N_2$(*5).

## E. Ion source operation with constant discharge current and potential

### Introduction

The electron impact ion source used in this experiment was originally designed by Colutron Inc., later modified by Amano(*1) and has been used in the low energy ion beam deposition system for many years. The main operational problem with this type of ion source is an unstable discharge condition which results in an unstable extracted ion beam current. Generally, the ion source discharge power supply can be set in two different modes: a constant voltage mode or a constant current mode. Each mode tends to stabilize the titled parameter by destabilizing the other parameter. The major disadvantage of the constant voltage mode is that the resulting fluctuating discharge current can force a premature shut down of the arc with only a small drop of source pressure. The constant current mode can be implemented with a slow shut down of the arc when the increased discharge potential can keep the arc. The necessary increase of discharge potential in this mode can keep the arc on if a small drop of source pressure occurs but this fluctuation of discharge potential produces a corresponding fluctuation of ion beam current.

To improve the characteristics of both modes of operation, a third mode: constant voltage with constant current is implemented in this experiment. The discharge power supply is set in the constant current mode and the optimum discharge potential is maintained by controlling the source pressure. This design of ion source incorporates two separate filaments: one for a furnace to evaporate a solid charge and the other in the discharge chamber to act as an electron emitter immediately in front of the furnace. This second filament also provides some extra furnace heating and this behaves as a fine control while the furnace heater acts as coarse control of the furnace temperature. The electron source filament temperature must be kept well above the point where the space charge saturated electron current can be emitted under the given ion source operational conditions. Therefore the lower limit of electron source filament current should be set and maintained above this limit at all times. The furnace and source filament power supplies are operated under constant current mode. As the filament wears out the supplied filament power increases because of the constant filament current. As the furnace or source filament power is increased, the source pressure is increased and the discharge potential tends to decrease.

The ion source now can be operated with three controllable parameters: the discharge current, the discharge potential and the discharge pressure. When any two parameters are set, the third is determined by the first two. In this case of a solid charge with the electron impact ion source the constant discharge potential and current is maintained by controlling the source filament while the furnace filament power controls the vapor pressure of the solid charge.

**Ionization efficiency and discharge potential**

With a given set of ion source parameters : source pressure, charge material and physical dimension of the source, the electron ionization efficiency , $S_i$ , is a function of the electron energy(*3). The number of ion pairs produced along a unit distance( 1 cm ) is given by,

$$dn^+/dt = S_i \, p \, I^- / e \text{ ------------------- } (4\text{-}21)$$

The discharge current comprises an electron current and an ion current. The ratio of the two currents is inversely proportional to the square root of their mass. In the case of a metallic ion species, the electron current is over 99% of the discharge current. Usually the electron supply from the cathode is limited by the power supply capability, the geometry of the ion source and the cooling capacity . Normally the discharge current $I^-$ is set at a certain safe value considering the above limitations. The next parameter to be set is the source pressure. As the pressure is set, the discharge potential is determined by discharge current and pressure. The detailed relationship between discharge potential, current and discharge pressure is not well defined because it varies along the geometry of the source. Other factors such as the discharge power supply characteristics and the charge material also would have to be considered if the relationship were to be analyzed.

The experimental results show that under constant discharge current conditions, the discharge potential decreases as furnace or source filament power is increased, i.e as the source pressure is increased (Figure 4-5 ). The optimum source pressure and discharge potential which yield the maximum ion beam current can be determined experimentally. Once the optimum discharge potential is found, then a microprocessor controlled PID(proportional,integral and derivative) control system maintains this discharge potential by controlling the furnace and source filament power.

**PID control of ion source**

A conventional feedback control system using three modes(PID) is given by,

$$M(t)=Kc\{e(t)+1/\tau_i\int_0^t e(t)dt+\tau_d de(t)/dt\}+M_s \quad \text{--(4-22)}$$

where

$M(t)$ ; controller output

$Kc$ ; proportional gain

$e(t)$ ; error

$\tau_i$ ; integral time

$\tau_d$ ; derivative time

$M_s$ ; steady state controller output that drives the error to zero

The digital equivalent of equation (4-22) is given by(*4),

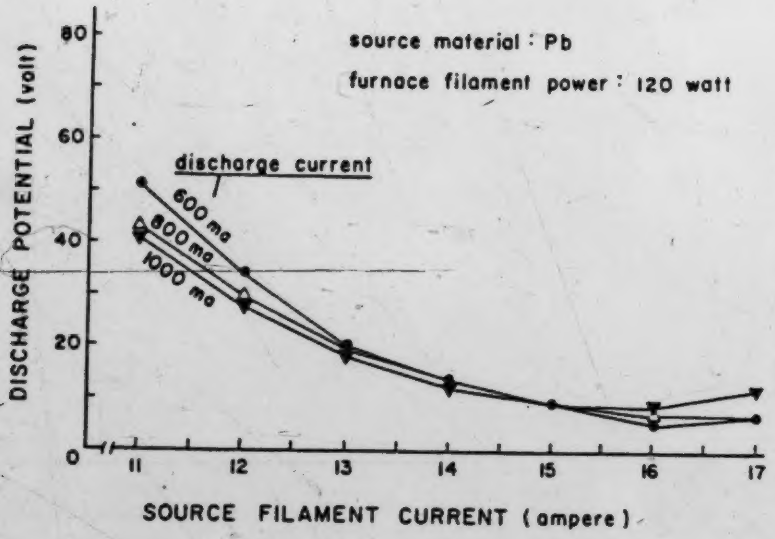


Figure 4-5 : Ion source discharge potential vs. filament current.

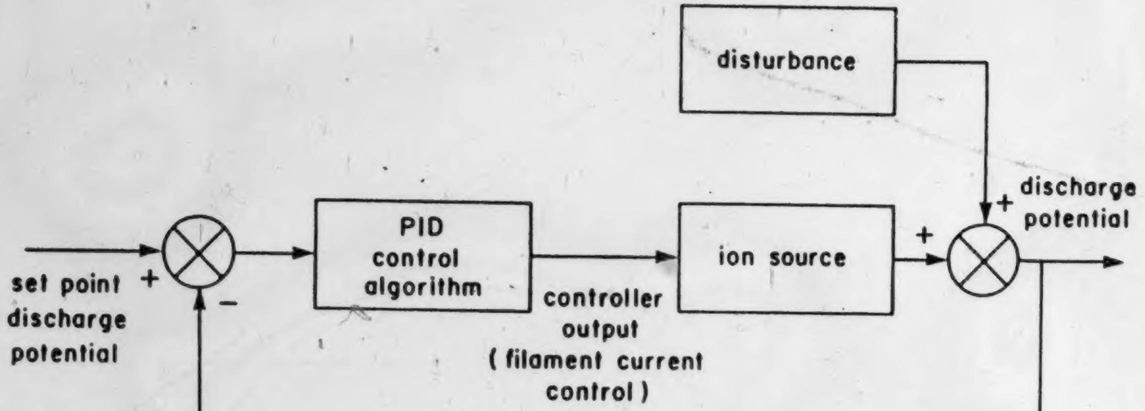

disturbance
PID
control
algorithm
ion source
set point
discharge
potential
+
−
controller
output
( filament current
control )
+
+
discharge
potential

Figure 4-6 : Ion source PID control.

$$M_n = Kc \{ e_n + T/\tau_i \Sigma e_i + (e_n - e_{n-1})\tau_d/T\} + M_0 \quad \text{--(4-23)}$$

where

$M_n$ ; controller output at nth sampling instant

$e_n$ ; error(set point - measurement ) at the nth sampling instant

$e_{n-1}$ ; error at the n-1 th sampling instant

$M_0$ ; steady state controller output that drives the error to zero

The equation (4-23) is transformed into the velocity form of equation (4-24) which is a convenient form to be implemented by a digital computer(*4).

$$M_n=M_{n-1}+Kc\{e_n-e_{n-1}+e_nT/\tau_i+(e_n-2e_{n-1}+e_{n-2})\tau_d/T\}$$

------------------ (4-24)

The control algorithm of equation (4-24) is implemented and the ion source operation has been tested using A/D and D/A channels. Figure 4-6 shows the block diagram of the ion source control. The controlled parameter is the discharge potential and the manipulated variable is the furnace filament(the pressure) and source filament current. A series of proportional gain, integral time and derivative time parameters have been tried in attempts to tune the controller. Figures 4-7a,b,c show the effect of the different proportional gains, integral time and derivative time on the ion source discharge potential. A high proportional gain caused an oscillation of discharge potential(Figure 4-7a). A large integral time setting yielded a lack of response to a shift of the controlled output(Figure 4-7b). A large derivative time caused an unnecessarily large reaction to a sharp noise pulse that might be in the discharge potential. The control parameters which gave a reasonable response were proportional gain, Kc(x $10^{-3}$) of 3 to 5, integral time, $\tau_i$ of $\approx$5T (where T is sampling interval, 0.5 sec ) and derivative time, $\tau_d$ of 0 T to 0.2 T.

## Results and discussion

The extracted $Pb^+$ ion current was measured with a Faraday cup. The extraction field strength at ion source anode is 2 kV/cm and the ion source control parameters are proportional gain, Kc=3 x $10^{-3}$, integral time, $\tau_i$=5 T, derivative time, $\tau_d$=0 T and the sampling interval, T=0.5 sec. The manual control result in Figure 4-8 shows that the ion current tends to decrease as time increases and the abrupt jumps every 15 or 20 minutes are caused by manual adjustments of filament power to restore the ion beam current. The ion beam current with PID control in action (Fig. 4-9) is much steadier. The constant voltage and current operation of the source gives a stable, high ion current output. When a gas is used in the ion source, a high precision gas flow controller which can be interfaced with the computer would produce a comparable operation to the results presented here with a solid charge.

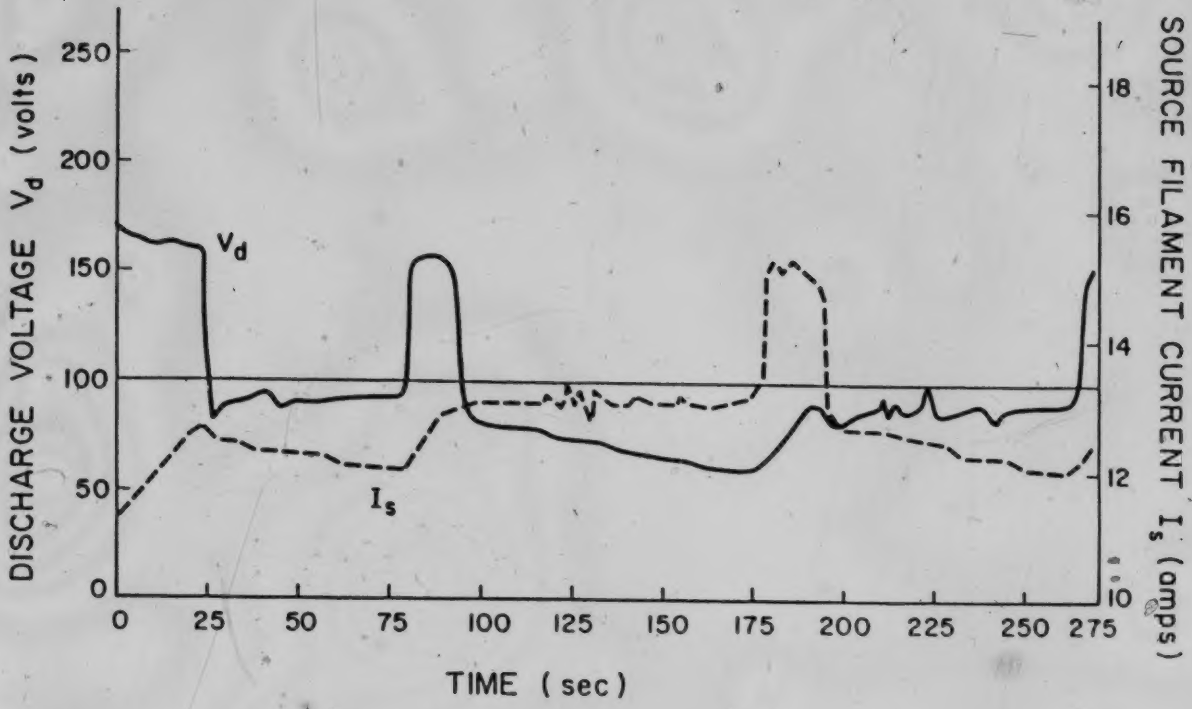


Figure 4-7a : Discharge potential control data -1
($Pb^+$, Id=600 ma, Vd=100 volt, Kc=0.007, $\tau_1$=5T, $\tau_d$=0.2T, T=0.5 sec.)

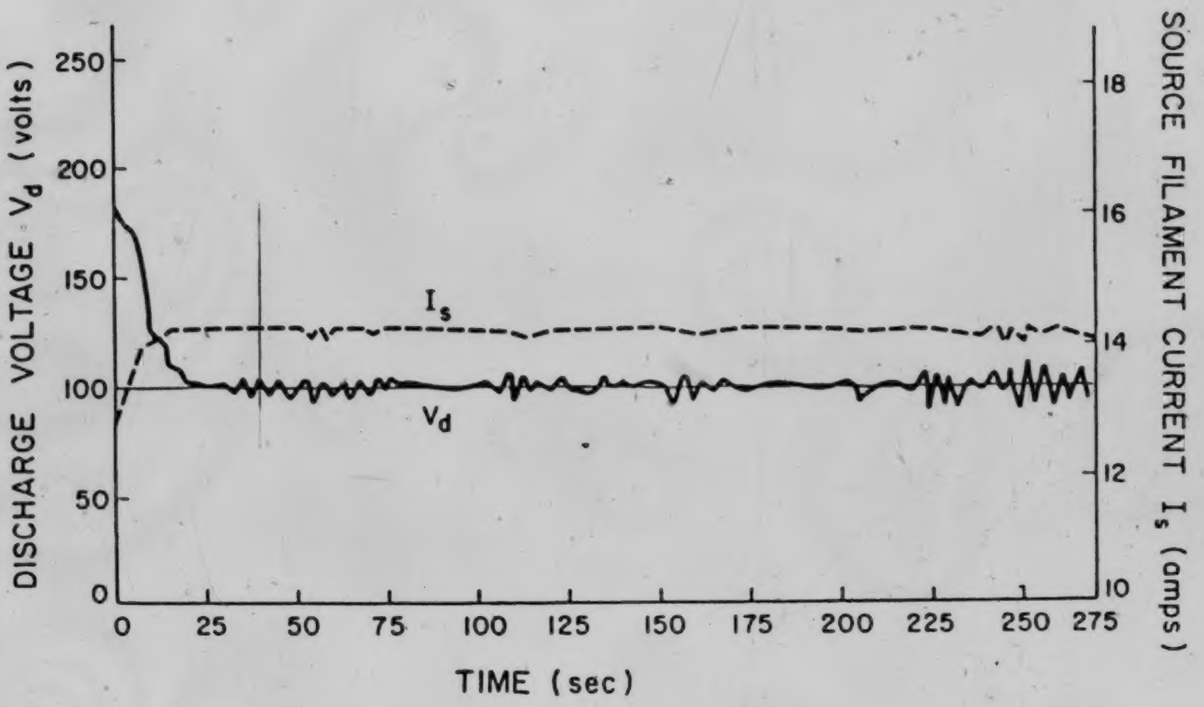


Figure 4-7b : Discharge potential control data -2
($Pb^+$, Id=600 ma, Vd=100 volt, Kc=0.0035, $\tau_1$=7T, $\tau_d$=0.2T,
T=0.5 sec.)

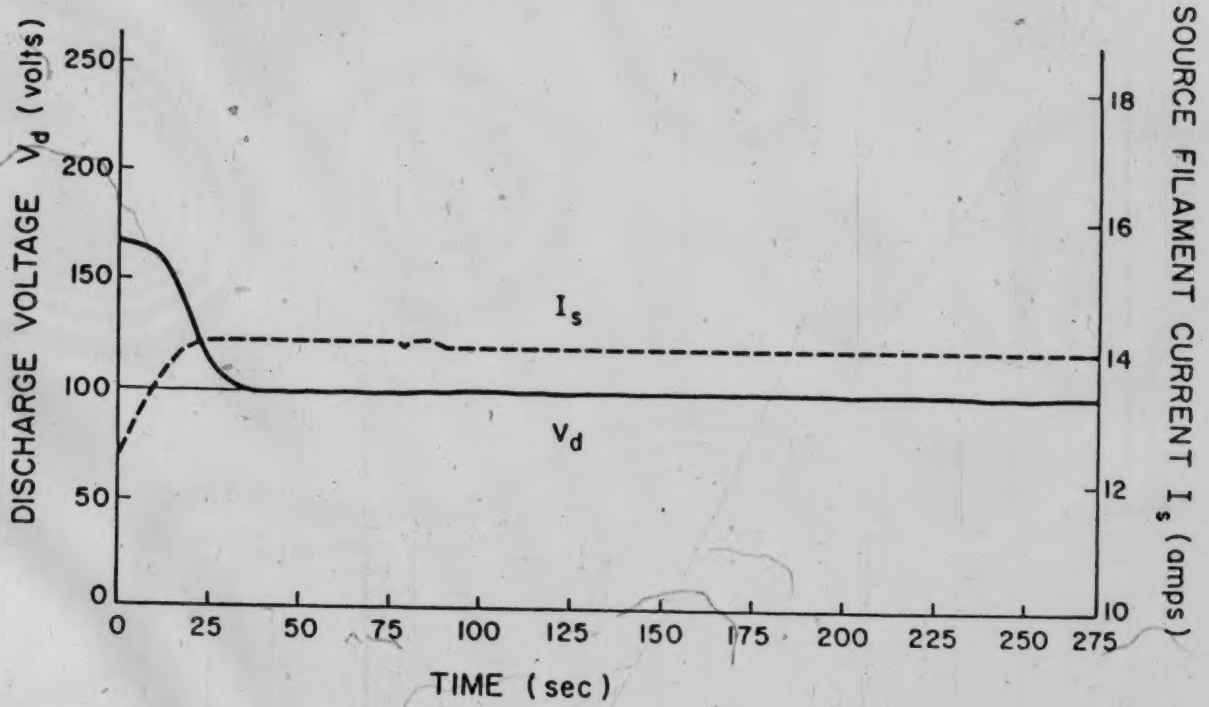


Figure 4-7c : Discharge potential control data -3 ($Pb^+$, Id=600 ma, Vd=100 volt, Kc=0.004, $\tau_1$=5T, $\tau_1$=0.2T, T=0.5 sec.)

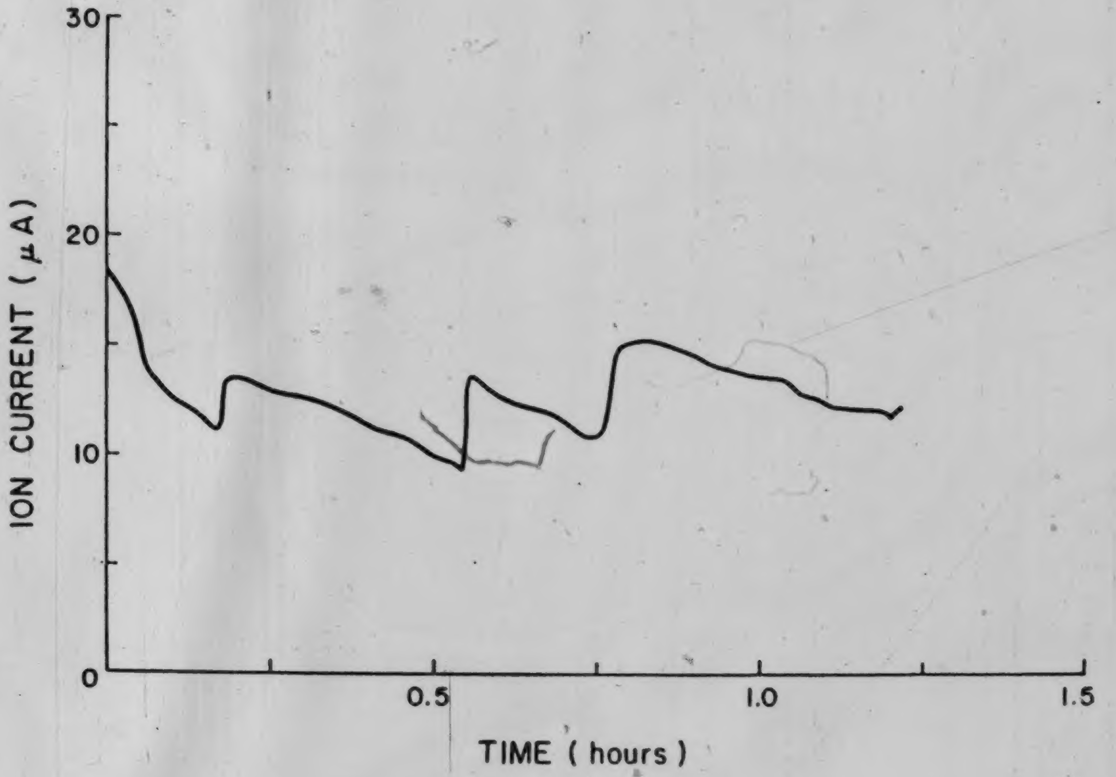


Figure 4-8 : Extracted ion current($Pb^+$) vs. time without PID control

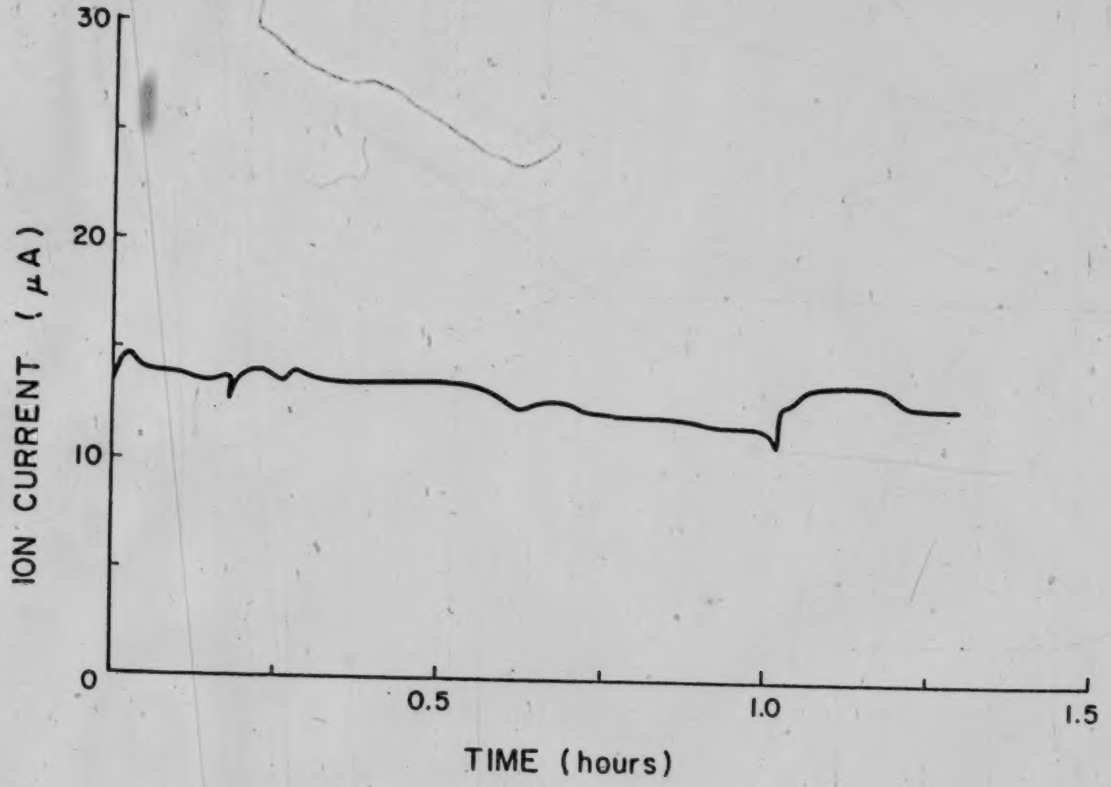


Figure 4-9 : Extracted ion current($Pb^+$) vs. time with PID control
(Id=600 ma, Vd=100 volt, Kc=0.003, $\tau_1$=5T, $\tau_d$=0.5T, T=0.5 sec.)

# V. System Hardware Specification and Design

6

## A. Introduction

The low energy ion beam system was initially designed and built by P. Bryce, J. Amano and R.P.W. Lawson in 1972 for low energy ion beam deposition studies. A major modification has been carried out in this work in order to handle sequential deposition of binary elements from the single ion source. The modification includes the design and implementation of a microprocessor controlled data acquisition and control system, a new ion source with two different temperature furnaces and a new target chamber decelerating lens within the substrate chamber. The ion source with two separate furnaces is able to produce two different ion species simultaneously and the microprocessor based control system selects one ion species at a time.

In binary alloy deposition, alternating thin slices of two different elements are sequentially laid and mixed during the film growth process. The composition ratio is controlled by the dosage ratio of each thin layer. The thin layer ranges from a few atomic layers to a few tens of atomic layers depending on the composition ratio and the high and low energy dosage ratio. The ion beam energy is programmed with low energy and high energy to enhance interdiffusion between the thin layers when a homogeneous alloy film is desired.

This chapter is divided into two major sections. In the first section, the ion beam system is described with an emphasis on the newly designed decelerator electrodes. In the subsequent section, the microprocessor-based data acquisition and control system is described.

### B. Ion beam system

The ion beam system comprises three major sections. They are an ion source chamber, an ion beam transport chamber and a target chamber. Each chamber is differentially pumped to maintain ultra high vacuum in the ion beam transport chamber and the target chamber while the ion source is in the pressure range of an arc discharge. A hot cathode electron impact ion source with dual furnace is housed in a water cooled jacket in the ion source chamber.

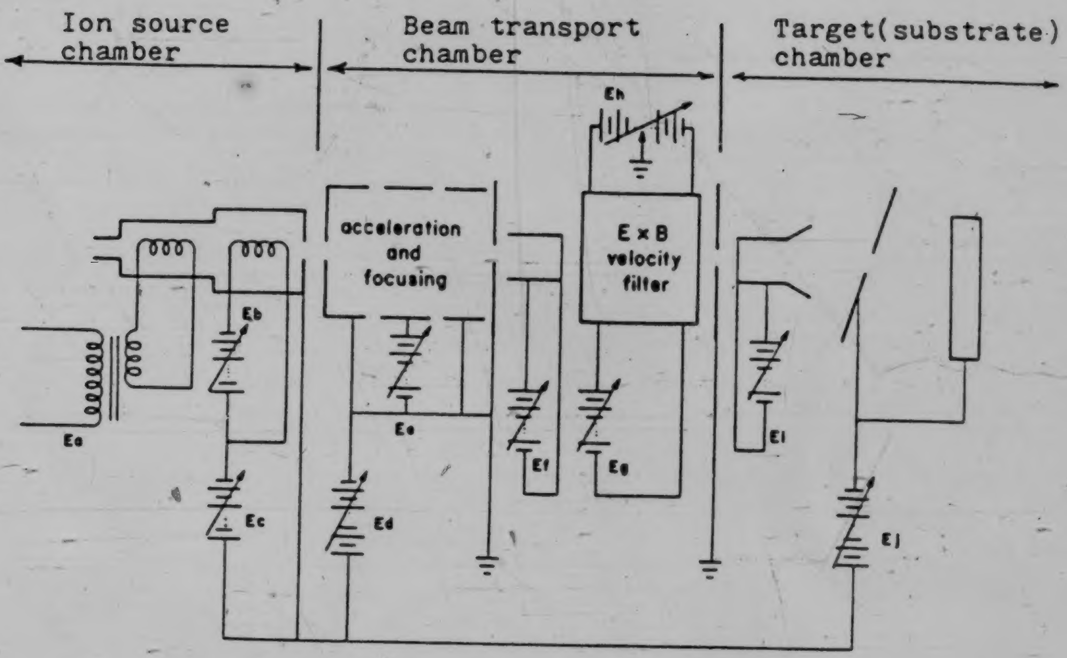
When two different temperature materials are fuelled into a single furnace, the partial vapor pressure of the high melting temperature material will be extremely low at a temperature which produces the required discharge chamber pressure of the lower melting temperature material. If the furnace temperature is raised to increase the vapor pressure of the high temperature material, the total pressure in the discharge chamber becomes too high to be efficient with electron ionization, and the vapor pressure ratio of the two materials would not be improved unless the vaporization of the low temperature material is suppressed.

To remedy this problem, a two-furnace concept is introduced. Even with two separate furnaces there are some operational difficulties because of the common discharge chamber. Considering the different ionization efficiency of the two materials used and the alloy composition ratio, the optimum vapor pressure ratio as well as the total pressure of two materials have to be set and maintained to maximize deposition efficiency. When the ion source discharge current and potential are set constant, the total vapor pressure has to remain constant. The change in the vapor pressure ratio results in a change of the ion current ratio of the two different ion species as well as the total current. Another difficulty with a dual furnace ion source is the level of thermal isolation between the two furnaces. If they are not well isolated from each other, the furnace with higher temperature will affect the other, resulting in poor control of the vapor pressure ratio.

The ion beam transport chamber houses an Einzel lens, an E x B velocity filter and a pair of vertical deflection electrodes. Ions are extracted from the source through a 60 mil anode hole at an extraction field of 2.3 kV/cm. The three-element cylindrical electrostatic Einzel lens focuses the ions so that they pass through the next stages with minimum loss and deliver maximum ion current onto the target. The E x B velocity filter counter balances the Lorentz force on a charged particle with a given charge to mass ratio using an electric field which is normal to both the magnetic field and ion trajectory. With a balanced condition, the selected ion species with a given charge to mass ratio will pass straight through while ions with different charge to mass ratios will be deflected. The electric field in the E x B velocity filter requires correction because the field near the end of the electrostatic plate is not straight. Usually a number of pairs of guard rings are used to correct the electric field in the E x B velocity filter. These guard rings are also used to form the ion beam into various cross-sectional shapes as necessary. A pair of vertical deflection plates are located at the exit of the E x B velocity filter to direct the ion beam trajectory vertically to deliver maximum target current.

The target chamber encloses a pair of horizontal deflection electrodes, a decelerator lens assembly and a target holder. Figure 5-1 shows the block diagram of the overall ion beam system. The following list gives the specifications of the ion beam deposition system(*1,2).

a. Ion source charge : gas, solid as desired.
b. Ion beam current : a few uA - a few tens of uA, depending on the charge material used.
c. Overall mass filtering resolution : $M/\Delta M=4$
d. maximum acceleration energy : 6 kV
e. Typical operating vacuum level
   Ion source : 0.1 - 0.01 torr
   Ion beam transport chamber : 1 x $10^{-7}$ torr


Ion source chamber
Beam transport chamber
Target(substrate) chamber
Eh
acceleration and focusing
E x B velocity filter
Eb
Ea
Ee
Ef
Eg
Ei
Ec
Ed
Ej

Ea: Ion source furnace filament power supply(16V/16A)
Eb: Ion source filament power supply(16V/20A)
Ec: Ion source discharge power supply(300V/1A)
Ed: Acceleration power supply(6KV/20ma)
Ee: Focusing lens power supply(5KV/1ma)
Ef: Vertical deflection power supply(300V/0.1A)
Eg: Magnet power supply(16V/16A)
Eh: Velocity filter E-field power supply(350V/0.1A)
Ei: Horizontal deflection power supply(350V/0.1A)
Ej: Ion beam energy power supply(400V/10ma)

Figure 5-1. The block diagram of ion beam system.

Target chamber : 1 x $10^{-8}$ torr

f. Film growth rate : about 1000 Å/hour (depending on ion beam current, deposition material and energy)

g. Ion beam energy spread : ≃ 30 eV ($Pb^+$ beam accelerated to 4 keV and decelerated to 50 eV)

Figure 5-2 shows the target chamber electrode configuration. Ions entering the target chamber are deflected about 6° horizontally to prevent energetic neutrals from reaching the target. The deflected ions enter the deceleration field isolator which is designed to provide a symmetric decelerating field between decelerator and isolator.

## Decelerator design

The main object of the decelerator lens design is to reduce the ion beam energy to a few tens of eV from the initial energy of a few keV without losing a large fraction of the ion beam current and without spreading the incident beam over too large a surface area. A number of different geometries of ion beam decelerating lens have been reported(*1,*3-6). The difficulty of designing a decelerating lens system in the low energy regime arises from the space charge expansion of the ion beam in the process of retardation. In the deceleration region the space charge expansion becomes significant due to the extremely low velocity of ions. Therefore a compensating focusing force is considered necessary to cancel out the space charge expansion force. To determine the optimum strength of

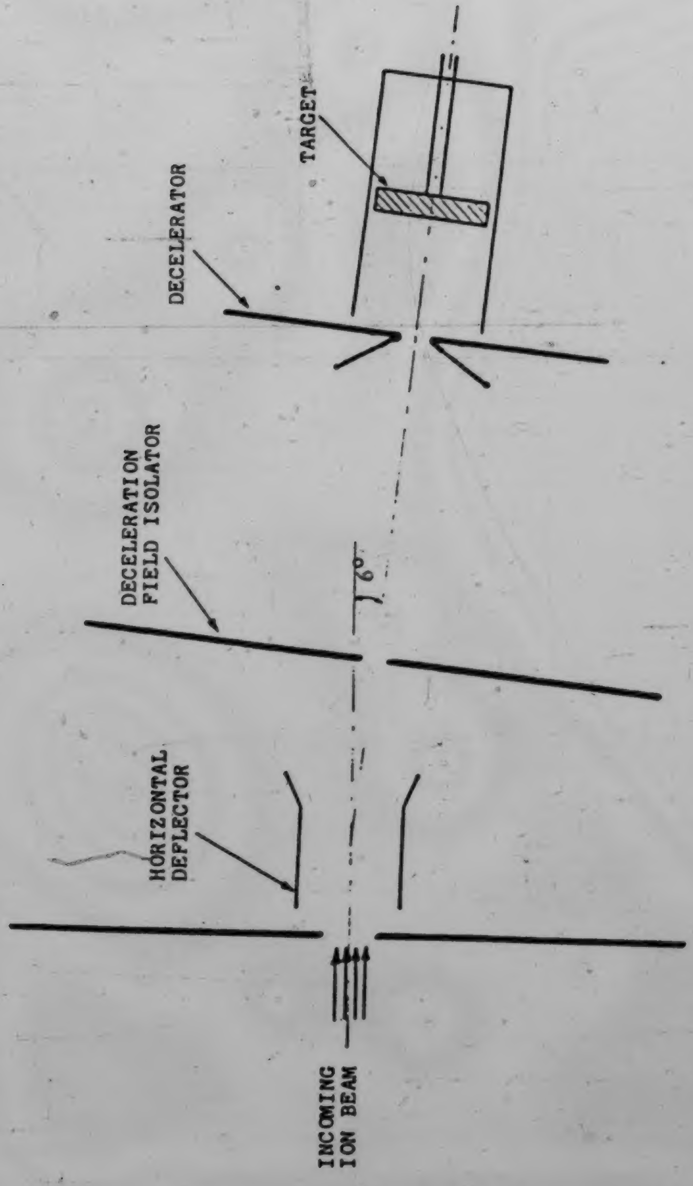

TARGET
DECELERATOR
DECELERATION FIELD ISOLATOR
6°
HORIZONTAL DEFLECTOR
INCOMING ION BEAM

Figure 5-2. Decelerator and target assembly.

focusing and the location of the focal point under a given incoming beam condition (the degree of convergence or divergence, the level of offset from main beam axis), a computer program has been written to solve the field in the decelerating region in order to simulate charged particle trajectories. To verify the computer simulation results, electrodes were constructed and ion beam current and deposition patterns were monitored. In solving for the field pattern, the effect of the charge of the introduced particles to the existing field is not considered. In the particle trajectory calculations, only a single particle is introduced at a time in the field and therefore no space charge effect is included. Therefore the real trajectory would be less convergent than the simulation results.

The basic idea of the new geometry of the decelerator electrode was given by the well known Pierce electrode system(*7) which normally has been used for electron or ion gun design. A charged particle gun and a charged particle decelerator with a particle collector are similar in terms of particle trajectories: if we replace a charged particle which is being accelerated in front of the gun, with an identical particle at the same position with an opposite velocity vector with the same magnitude, then the replaced particle travels the same trajectory which the original accelerated particle made, while being decelerated moving towards the gun. Therefore an extraction and acceleration geometry which can produce a well focused charged particle beam can also make a good decelerator.

The target in the cylindrical target holder is moveable to set an appropriate ion beam deposition area. The decelerator and target holder assembly is rotatable to optimize the offset position of the decelerator. The ion beam current collected by the decelerator, target holder and target can be monitored separately to identify ion beam loss. From Figure 5-3 and 5-4, the outside rectangular boundary is at ground potential (target chamber stainless steel wall) and the electrodes in the middle are at 3950 volts. Each equipotential line represents an increase of 100 volts starting from the boundary and moving towards the decelerator and target electrodes in the middle. The initial energy of incident particles is 4.0 keV and the particle energy falls to 50 eV while the particles are decelerated and collected by either the decelerator or the target. Figure 5-3 shows 20 particle trajectories whose incident converging angle $\theta$ is given as, $\theta=\tan^{-1}0.005$, and the distance between lines at the inlet is 0.5 mm. The initially converging beam introduced into a cylindrical decelerating lens shows a well maintained beam onto a small area without a strong divergence after retardation. But the initially divergent beam into the same lens shows strong focusing action and becomes a strong divergent beam when it reaches the target(Figure 5-5d). The conical Pierce type decelerating lens seems more promising than a cylindrical lens in producing a high density deposition onto a

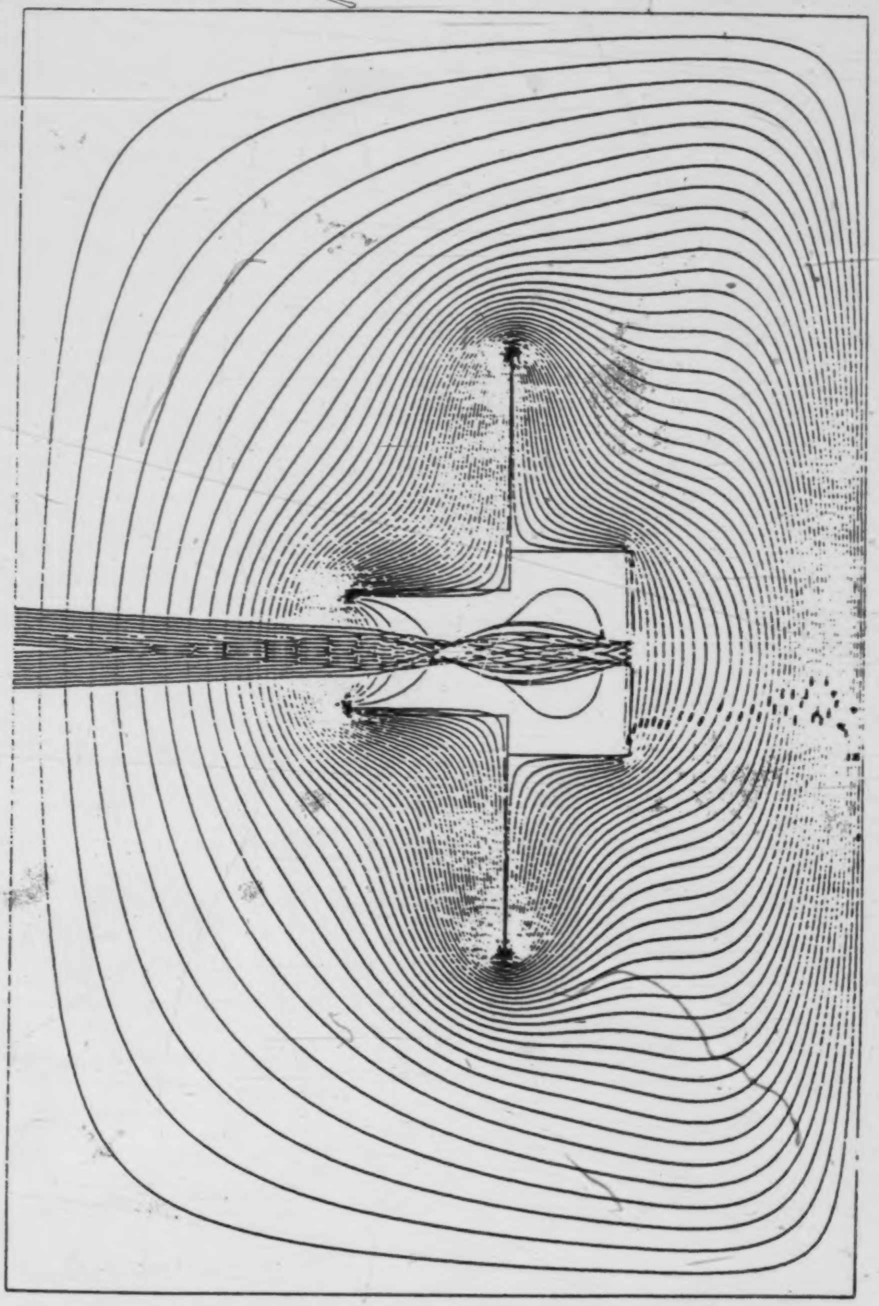


Figure 5-3. Ion trajectories and equipotential lines with a cylindrical decelerator.(the incident converging angle $\theta=\tan^{-1}0.005$, initial offset=0.5mm/line)

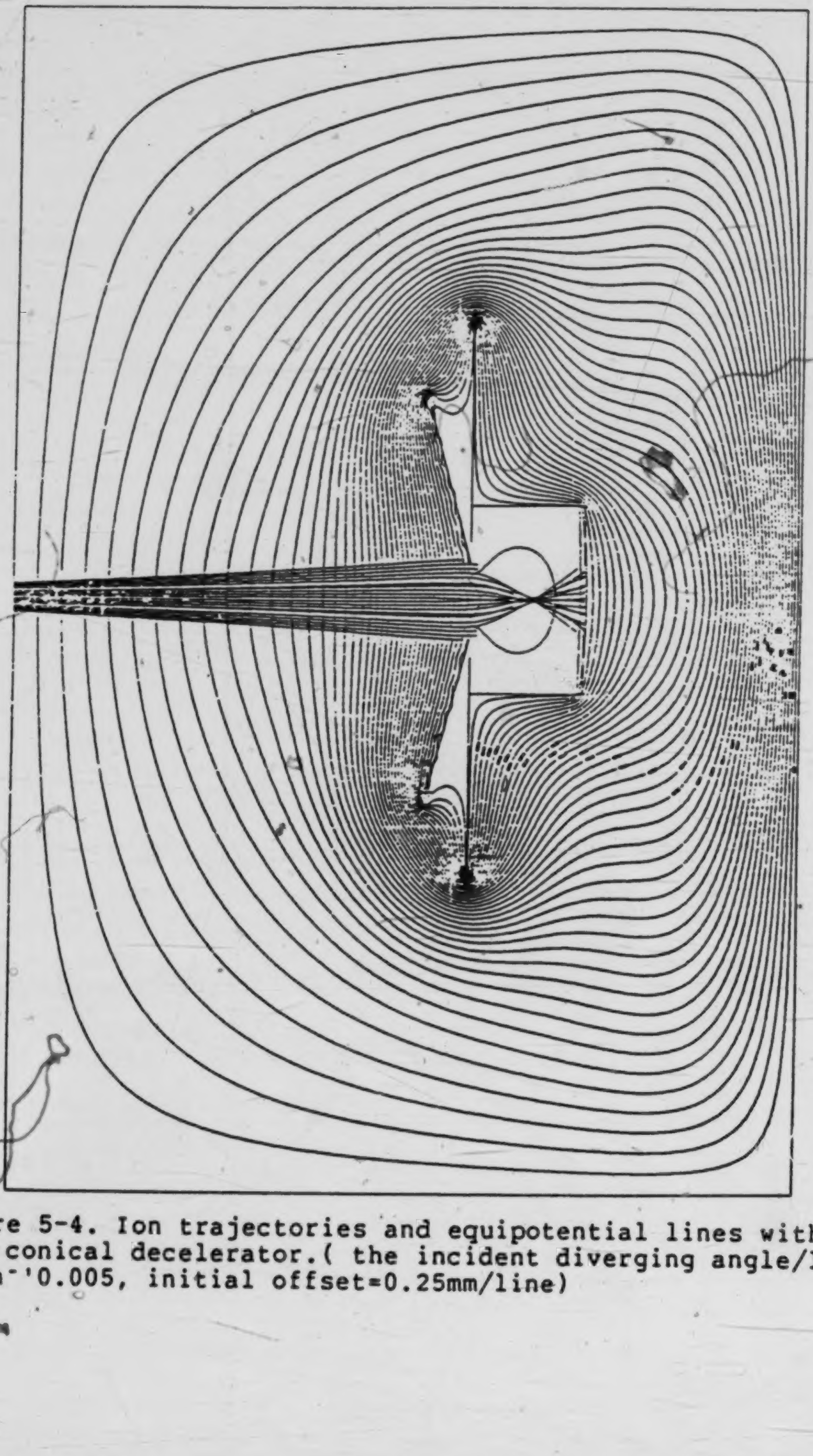


Figure 5-4. Ion trajectories and equipotential lines with a 150° conical decelerator.( the incident diverging angle/line $\theta=\tan^{-1}0.005$, initial offset=0.25mm/line)

relatively small area. Figure 5-4 and 5-5a,-5b,-5c show the lens effect of the conical electrode with different cone angles. With a large cone angle, the focusing effect is too weak (Figure 5-4, cone angle of 150°) and a considerable portion of beam is lost by hitting the decelerator electrode. A too small cone angle produced a similar result with the cylindrical electrode; a too strong focusing effect( Figure 5-5a, 5c, cone angle of 60°).

A cone angle of 90° was selected after performing these simulations and analysing actual ion beam current measurements. With this new geometry, the ion beam density increased by a factor of 5 compared with a conventional diaphragm decelerating lens system.

**Ion beam energy spread measurement**

Generally the ion beam energy spread of a hot cathode electron impact ion source is 1 - 10 eV(*8). When the same ion source is used in an ion beam system and the extracted beam is transported a considerable distance, the ion beam energy spectrum changes resulting in more low energy ions and low energy tailing enhances as chamber pressure is increased(*9). Figure 5-6 shows the ion current change verses the retarding potential change and Figure 5-7 shows the ion energy spectrum which is obtained from Figure 5-6 and 5-8 by differentiating the ion current with ion energy. Ion beam energy spread is measured with a $Pb^+$ ion beam, at various discharge currents and potentials at an acceleration

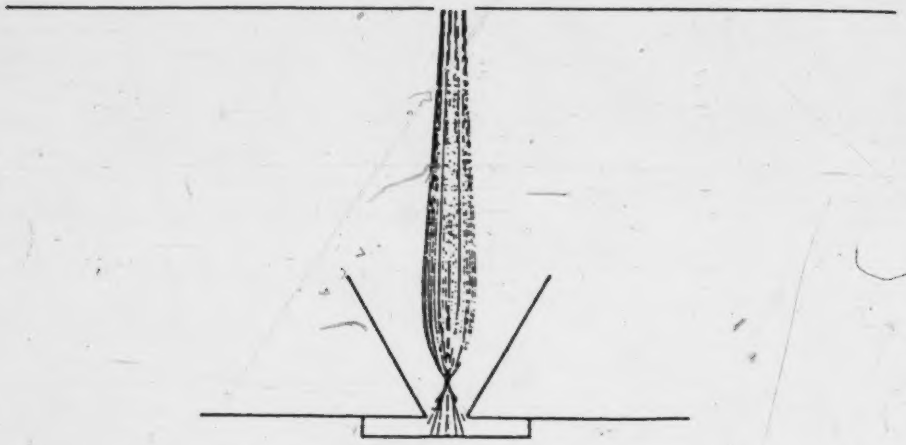


Figure 5-5a. Ion trajectories with a 60° conical decelerator.(the incident diverging angle/line $\theta=\tan^{-1}0.005$, initial offset=0.25mm/line)

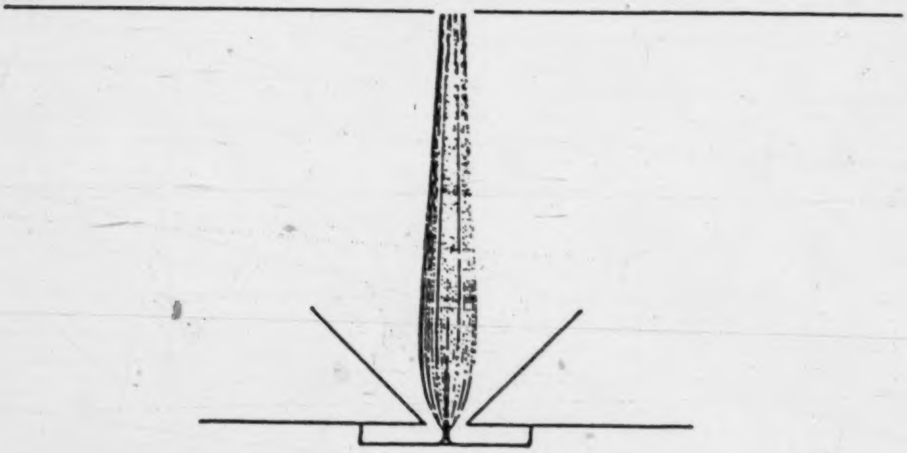


Figure 5-5b. Ion trajectories with a 90° conical decelerator.(the incident particle conditions same as 5-5a)

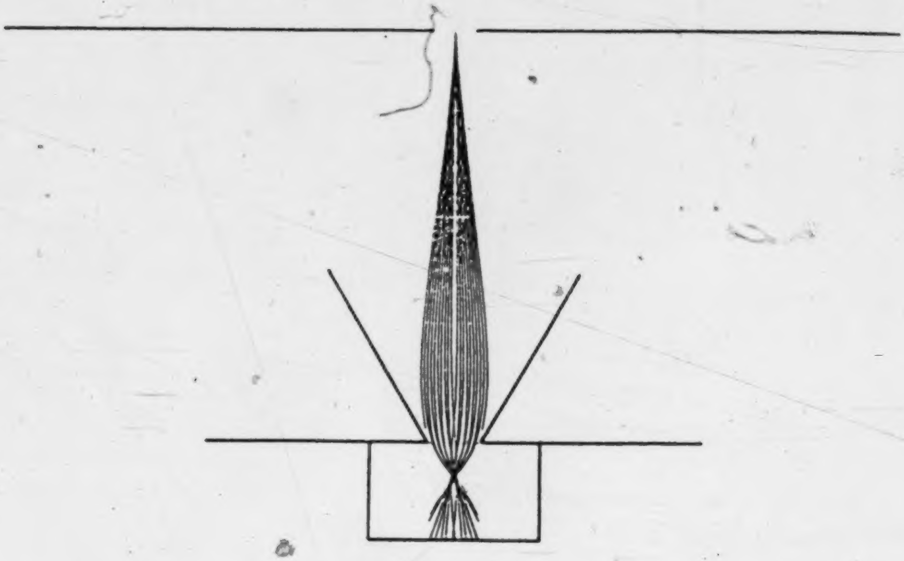


Figure 5-5c. Ion trajectories with a 60° conical decelerator.(the incident diverging angle/line $\theta=\tan^{-1}0.01$, no initial offset)

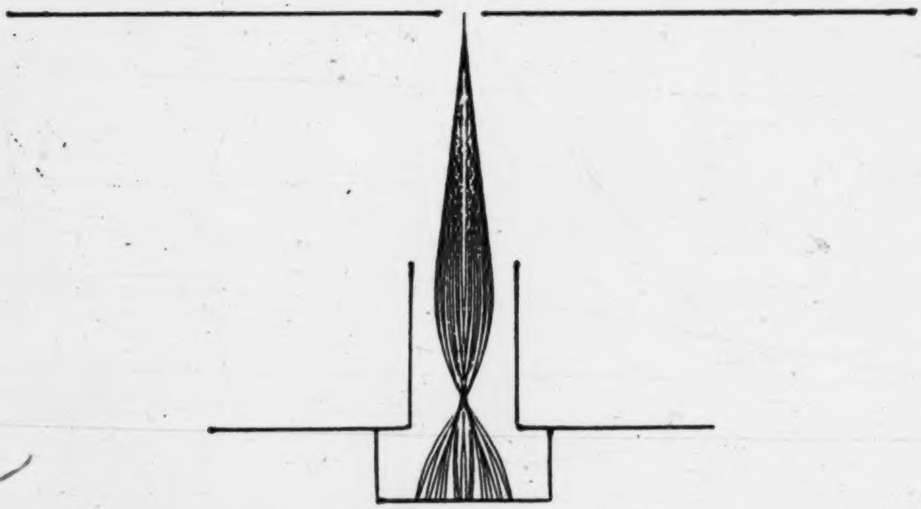


Figure 5-5d. Ion trajectories with a cylindrical decelerator.(the incident particle conditions same as 5-5c)

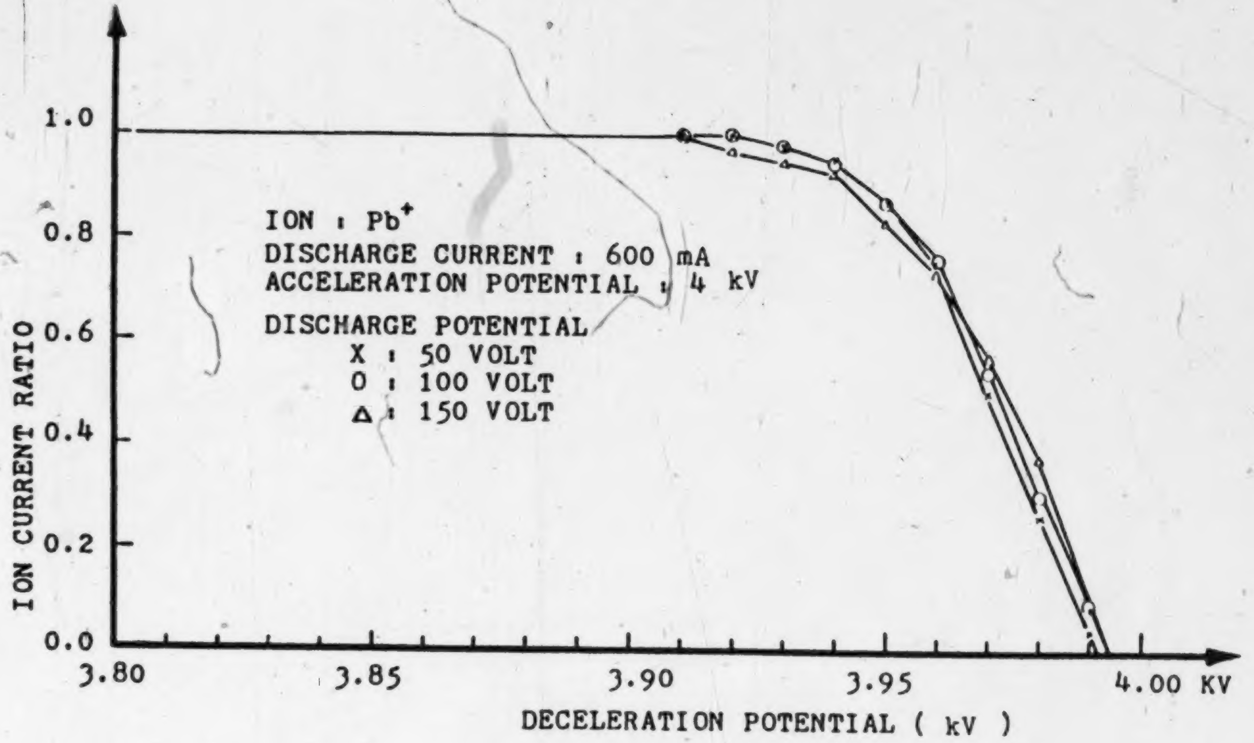


Figure 5-6. Ion current vs. decelerator potential

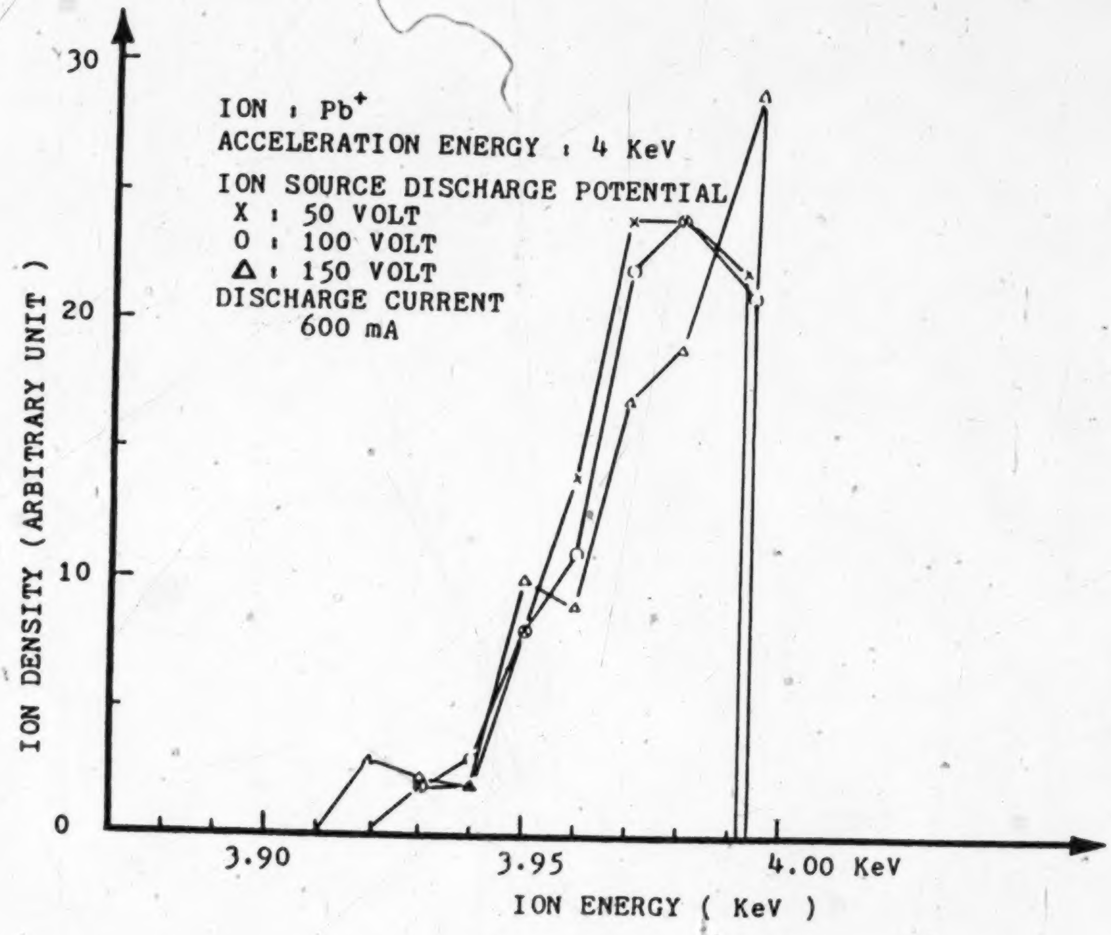


Figure 5-7. Ion beam energy spread with different ion source operating conditions.

potential of 4 kV. Ions produced from the ion source with low discharge potential show that about 99.5% of available ions in the target chamber are collected at the target when the deposition beam energy is set at 50 eV. The overall energy spread with a 4 KeV beam in this ion beam system is about 30 eV. It varies with ion source operating conditions, the chamber pressure, the distances travelled by the ions and ion optical conditions. The ion extraction characteristics have been measured with a Faraday cup with a secondary electron suppressor. While maintaining the ion source discharge conditions constant, the extraction potential is varied while monitoring the ion current at the Faraday cup (Figure 5-8). At extremely low potential(<200 V), it shows the space-charge-limited current curve which features the proportionality of current to $V^{2/3}$. As the extraction field is increased gradually, the curve moves towards an emission limited mode. Unlike the electron extraction characteristics, the transition region between space-charge-limited and emission-limited is wide, because the fluid-like ion emitting surface of plasma adapts itself to the extraction field to maintain space-charge-limited current until the extraction field cannot penetrate any further into the discharge chamber.

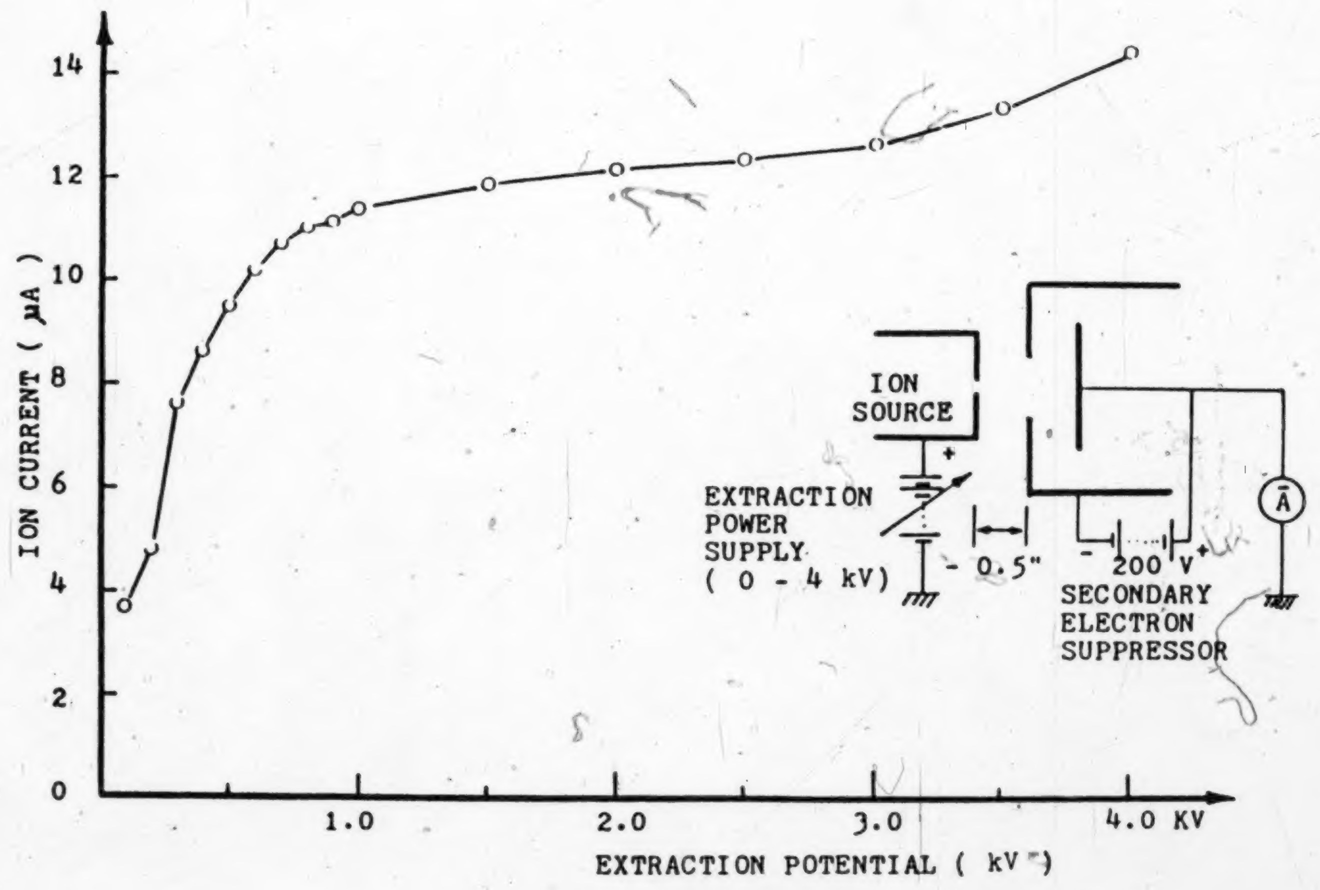


Figure 5-8. Ion current vs. extraction potential

### C. Data acquisition and control system

The ion beam deposition system was originally designed for single-element and single-energy deposition. For binary element deposition, a few different system configurations have been considered. The simplest but most costly configuration is one with two identical ion beam lines which are directed onto a common target in a target chamber. This configuration has the advantage of co-deposition which enables two different elements to be deposited and mixed simultaneously but has the disadvantage of high system cost. As an alternate method, sequential deposition of two different elements was considered. Sequential deposition is more economical because only one beam line is required but has the disadvantages of a complex control hardware and the limitations of one ion source using binary element charges.

The computer controlled data acquisition and control system was designed and implemented here to change the single element deposition system into a binary element sequential deposition system(*10). The data acquisition and control system hardware comprises five major functional blocks: 1) an IBM PC as a master computer, 2) a MC6809 microprocessor based system as a slave computer, 3) 32 channel A/D and a multiplexer, 4) 24 channels D/A, 5) 16 channel AC load controllers and a multiplexer(Figure 5-9). Because the ion source, the target and the decelerator are located at a high positive voltage, the power supplies related to these must be floated at the high voltage.

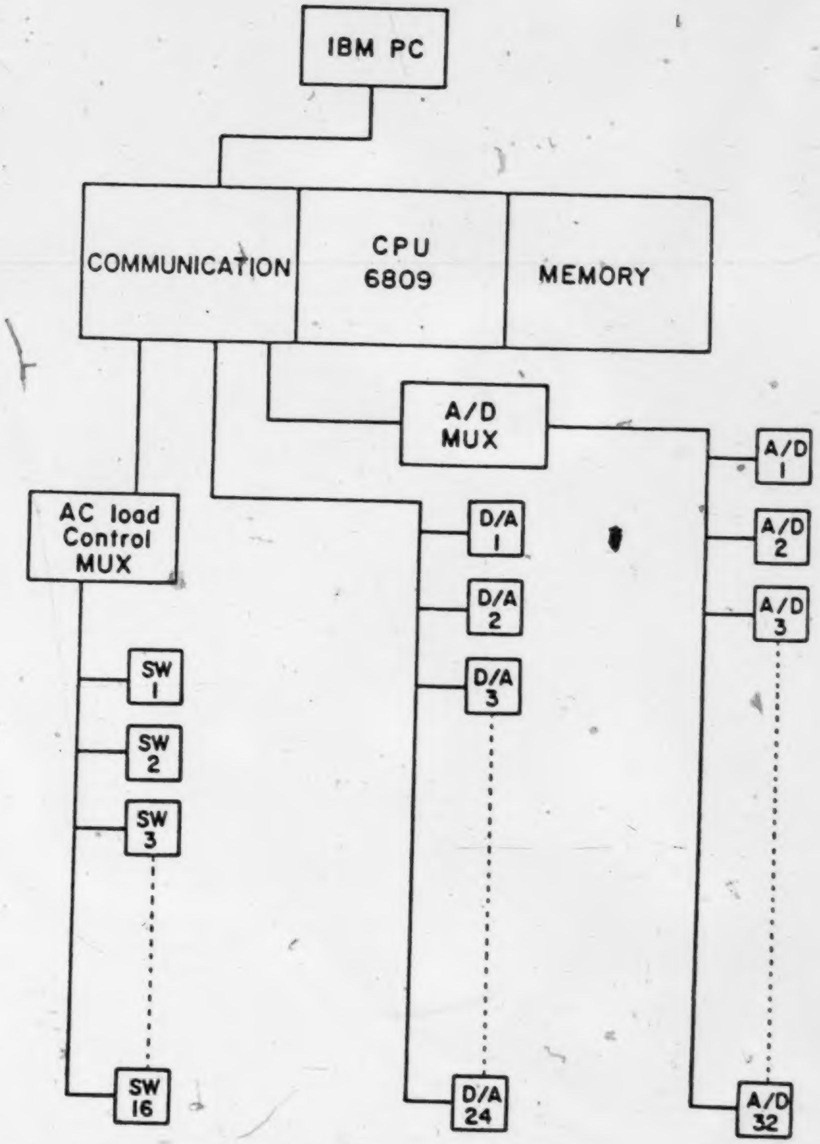

IBM PC
COMMUNICATION
CPU
6809
MEMORY
A/D
MUX
AC load
Control
MUX
SW
1
SW
2
SW
3
SW
16
D/A
1
D/A
2
D/A
3
D/A
24
A/D
1
A/D
2
A/D
3
A/D
32

Figure 5-9. The block diagram of the data acquisition and control system.

Therefore the data acquisition and control lines entering these power supplies must have isolation higher than the floating potential. Each of the A/D and D/A units are isolated from each other by 7.5 kV. As a result the A/D and D/A units can be located at any potential up to the rated isolation and the output lines can be connected to the slave computer communication interface without any danger of damaging the slave computer.

### 1) Slave microcomputer

The slave microcomputer was designed with the Motorola MC6809 microprocessor family to handle the front end A/D, D/A and AC load control channels. It was built in three separate plug in cards, the CPU board , memory board and communication board. The CPU board has the CPU, bus buffers, bus driver and timer modules. The memory board contains 16 K bytes of RAM and 4 K bytes of EPROM. The communication board contains four separate communication interfaces(A/D, D/A, AC load control and IBM PC). Figure 5-10 shows the block diagram of the slave microcomputer system. The basic design specifications are as follows ;

- CPU : MC6809
- Clock frequency : 4.0 MHZ
- Memory : 16 K bytes static RAM, 4 K bytes EPROM, total 20 K bytes
- Communication interface to IBM PC : RS-232, 20 mA current loop, Baud rate : software controllable,

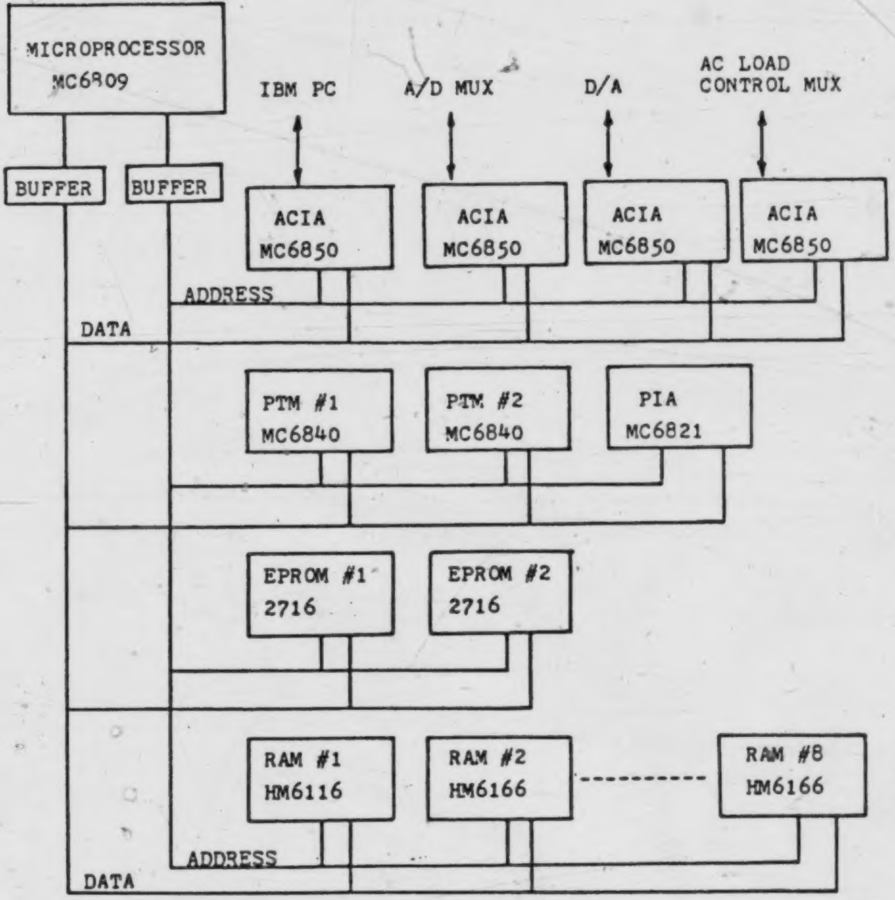

MICROPROCESSOR
MC6809
BUFFER
BUFFER
IBM PC
A/D MUX
D/A
AC LOAD CONTROL MUX
ACIA
MC6850
ACIA
MC6850
ACIA
MC6850
ACIA
MC6850
ADDRESS
DATA
PTM #1
MC6840
PTM #2
MC6840
PIA
MC6821
EPROM #1
2716
EPROM #2
2716
RAM #1
HM6116
RAM #2
HM6166
RAM #8
HM6166
ADDRESS
DATA

Figure 5-10. The block diagram of slave computer.

currently set at 2400 baud, Optically isolated communication lines

- Communication interface to A/D multiplexer : Asynchronous serial communication, Baud rate : 3555 baud
- Communication interface to D/A : Asynchronous serial communication, Baud rate : 3555 baud
- Communication interface to AC load control multiplexer : Asynchronous serial communication, Baud rate : 3555 baud
- Clock modules : two MC6840 programmable timer modules which run 6 separate clocks.

**2) Analog to digital conversion unit**

Multichannel A/D units can be configured in different ways. In order to specify the requirements we must consider the signal source frequency, the required resolution and accuracy, the number of channels to be monitored, sampling rate, signal environment and the cost. Some of the configurations are ;

- Direct conversion,
- Preamplification and conversion,
- Sample-hold and conversion,
- Preamplification, sample-hold and conversion.

Depending on the location of the multiplexer, the system configurations are ;

- Multiplexing the output of a single channel converter,
- Multiplexing the output of a sample-hold,
- Multiplexing the input of a sample-hold.

First we have to characterize the analog signal to be monitored in the ion beam deposition system in order to determine the most suitable configuration for the A/D units. All expected analog signals are mainly from various DC power supplies and a few ionization gauge controller outputs which are also DC. Any high frequency components in the signal are considered to be noise and must be eliminated with a low pass filter. When the signal source is DC, a simple A/D configuration of preamplification, filtering and conversion will be adequate. When determining the location of multiplexer, the isolation requirements of the A/D converter the inputs became a major factor. The multiplexer had to be located after the A/D conversion and multiplex digital output, because each A/D unit was at a different floating potential.

The overall configuration of the A/D unit is in the sequence of; analog signal - preamplification - low pass filtering - A/D conversion - multiplexing - microcomputer interface (Figure 5-11). An 8 bit successive approximation A/D converter with serial I/O, ADC 831 was used with each A/D channel. The serial I/O feature of the A/D converter has the advantage of reducing the number of isolated ports and allowing the unit to be located far away from the computer.

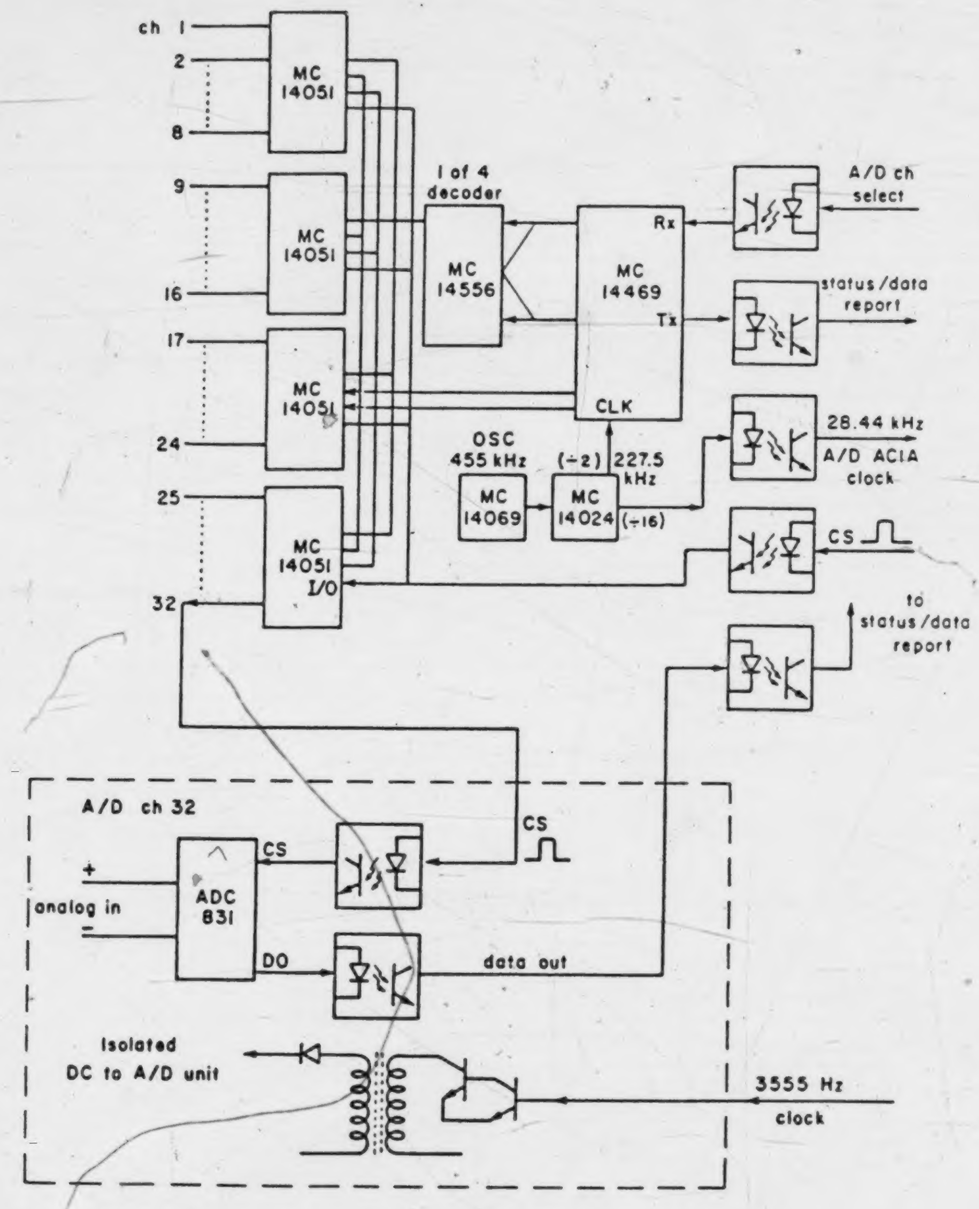

ch 1
2
8
MC 14051
9
16
MC 14051
17
24
MC 14051
25
32
MC 14051 I/O
1 of 4 decoder
MC 14556
MC 14469
Rx
Tx
CLK
A/D ch select
status/data report
28.44 kHz
A/D ACIA clock
OSC 455 kHz
MC 14069
(÷2)
227.5 kHz
MC 14024
(÷16)
CS
to status/data report
A/D ch 32
CS
+
analog in
−
ADC 831
CS
DO
data out
Isolated DC to A/D unit
3555 Hz clock

Figure 5-11. The block diagram of A/D unit and multiplexer.

Only two lines, one data and one control, have to be isolated with a serial I/O A/D unit.

The required power to run each A/D unit has been provided through an isolated pulse transformer which is run with a 3555 HZ clock pulse. The pulse transformer provides the clock pulses as well as power to run the A/D converter. The A/D multiplexer consists of a remote addressable transmitter/receiver, and four eight channel analog switches. The remote addressable transmitter/receiver is linked to an asynchronous communication interface adapter(ACIA) of the microcomputer system. One of the 32 analog switches is turned on according to a two byte command given by the microcomputer. The basic specifications of the A/D units are as follows:

- A/D converter : ADC 831, 8 bit successive approximation converter
- Conversion time : 2.25 msec( at conversion clock of 3.555kHZ)
- RC low pass filter time constant : 0.1 sec
- Analog input range : 0 - 2.5 Volt
- A/D converter reference : Zener diode reference, LM385-2.5(2.5 volt)
- Electrical isolation between analog input and digital output : 7.5 kV
- A/D conversion clock : 3.555 kHZ

Multiplexer unit

- Maximum number of channels : 32 channels

- Electrical isolation between I/O : 7.5 kV
- Communication data rate : 3555 baud
- Data response time(time from A/D data request to the end of digital data transmission) : 13.5 msec
- sampling interval : 0.5 sec.

**3) Digital to analog conversion**

An 8 bit D/A converter(an AD558) was used for the D/A units. Each D/A unit has a remote addressable asynchronous receiver/transmitter which can be addressed directly from the microcomputer without going through a multiplexer. Thus the access time is shorter than that of the A/D units which do have a multiplexer. The D/A converter and the remote addressable receiver/transmitter float at various different controller potentials, hence the analog and digital signal lines on each D/A unit were optically isolated with a 7.5 kV rating. Like the A/D units, the required isolated power was provided through an isolated pulse transformers. Figure 5-12 shows the block diagram of the D/A unit. The microcomputer sends out a two-byte command corresponding to a particular unit number and data, then the corresponding unit responds with its unit number and new output value. If no response is received at the expected time the addressed unit is considered to either not exist or be malfunctioning. The time required to set a new analog signal for a receiving D/A unit is 5.6 msec, this is considerably shorter than the A/D

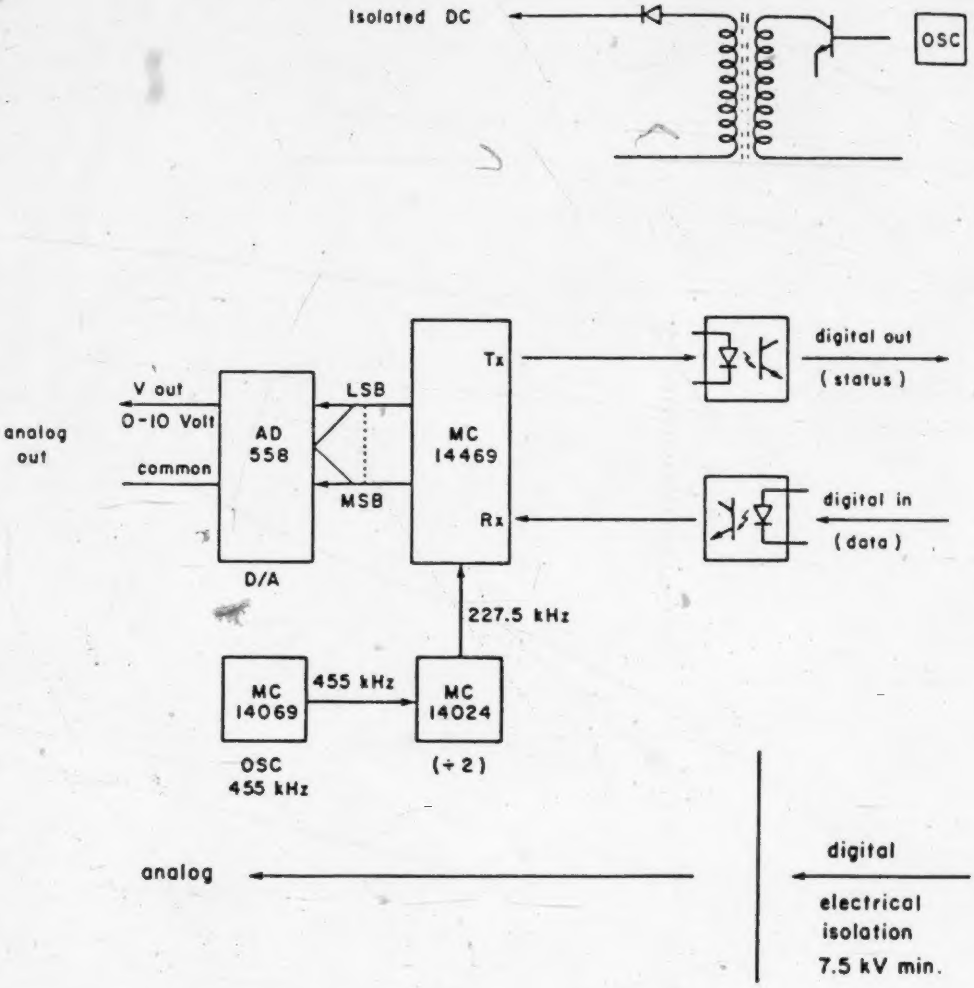

Isolated DC
OSC
Tx
digital out
( status )
V out
0-10 Volt
LSB
analog
out
AD
558
MC
14469
common
MSB
digital in
Rx
( data )
D/A
227.5 kHz
MC
14069
455 kHz
MC
14024
OSC
455 kHz
(÷2)
analog
digital
electrical
isolation
7.5 kV min.

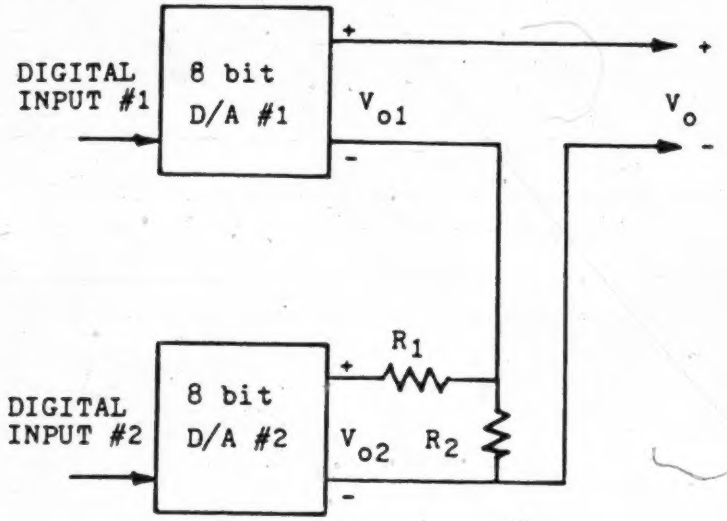
Figure 5-12. Block diagram of a D/A unit.

unit response time of 13.5 msec. The communication rate between the D/A unit and microcomputer is 3555 baud.

Most of the power supply controls produced satisfactory control resolution with an 8 bit D/A controller except the ion source filament power supply control and the Einzel lens power supply control. These two power supplies require a higher control resolution to set the system at optimum focusing and discharge potential. Using two 8-bit D/A units in series, the controller resolution was increased to 11 bits. The digital input to both D/A units were software-controlled so that 8-bit base converter(#1 D/A from Figure 5-13) produced the multiples of ($1/2^3$ x fullscale) output while the second converter(#2 D/A from Figure 5-13) produces the remaining part of the output with a resolution of (fullscale x $1/2^8$ x $1/2^3$). Even though the response time for these series controllers was increased by a factor of two, the higher control resolution while maintaining the high control dynamic range, produced satisfactory results to Einzel lens focusing and ion source filament power control.

**4) AC load control units**

The ion beam deposition system uses a number of AC motors which are attached to equipment such as rotary vacuum pumps, a water pump, a heat exchanger, solenoid valves, and a number of power supplies and heating elements for diffusion vacuum pumps. The safe operation of the total system required a strict on-off sequence: under certain


DIGITAL INPUT #1
8 bit D/A #1
+
-
$V_{o1}$
+
$V_o$
-
DIGITAL INPUT #2
8 bit D/A #2
+
$R_1$
$V_{o2}$
$R_2$
-

$R_1/R_2 = 2^n - 1$

$R_2 \ll Z_{in}$

where n : bit increment

$Z_{in}$ : power supply control input impedance

$V_{o1}$ : 8 bit resolution.
set to multiples of 5.0/n(volt).

$V_{o2}$ : 8+n bit resolution.

Figure 5-13. D/A resolution increase with two D/A units in series.

circumstances both the decision and action to operate a valve or to switch a power supply must be rapid to avoid damage. A number of AC load controllers, each using a triac and a load current transformer are accessed through an AC load control multiplexer from the slave microprocessor. (Figure 5-14). The slave sends one byte of multiplexer address and another byte of command whose lower 4 bits represents the unit number while the upper 4 bits represents the switch control commands. The switch control commands are: 1-read switch status only and do not alter switch status, 2-read current status and turn on switch if it is not on, 3-read current status and turn off switch if it is not off. The load switching capability is 15 A at 115 V 60 HZ. The status for each controller is sensed by a current sensor. Three different ranges of current sensors were made to handle different sizes of load current; a heavy load sensor for 3-15 Amp. range , a light load sensor for 5-0.075 Amp. range and a very light load sensor for less than 100 mA range. The former two range sensors are made in a similar fashion to a toroidal current transformer 0.5 inch diameter and 0.25 inch high. The third sensor is made using the forward voltage drop across a diode when the diode is forward biased. The current sensors were not designed to produce a correct current readings but are intended to be used to identify whether the load is turned on or off, or a fuse is blown. The sensor output is compared with a certain threshold reference to produce binary information data on the load status. The binary information is compared with a control command and produces an error signal when the control command and status information are not compatible.

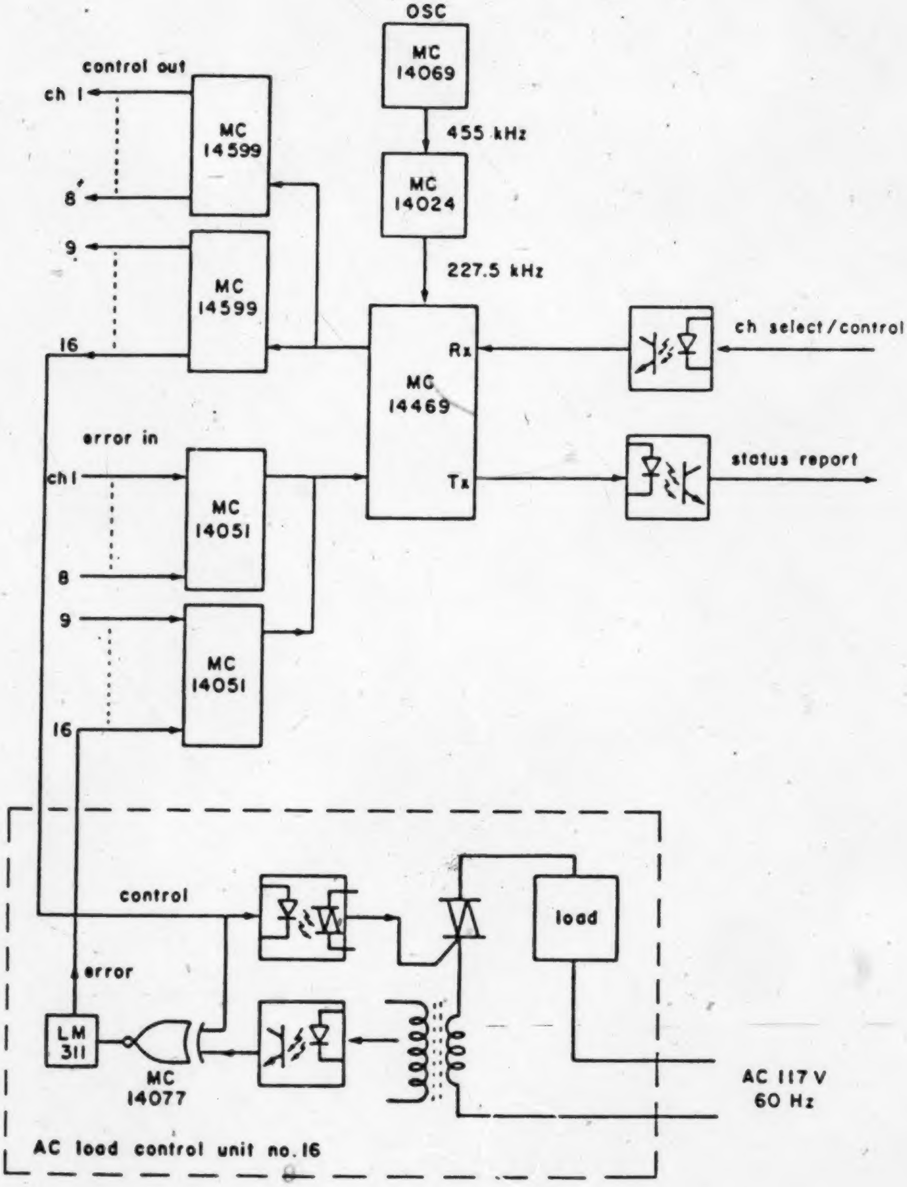

OSC
MC 14069
455 kHz
MC 14024
227.5 kHz
control out
ch 1
8
MC 14599
9
MC 14599
16
MC 14469
Rx
Tx
ch select/control
status report
error in
ch1
MC 14051
8
9
MC 14051
16
control
error
LM 311
MC 14077
load
AC 117 V
60 Hz
AC load control unit no. 16

Figure 5-14. The block diagram of AC load control unit and multiplexer.

# VI. Software Development for Sequential Ion Beam Deposition

The software for the ion beam deposition system is divided into three separate major programs; (1) the microprocessor system operating program, (2) the system startup and outgassing program and (3) the master operating program. The microprocessor program was written in 6809 Assembler while the latter two, for the IBM PC host computer were written in BASIC. The microprocessor unit is run by interrupts after initialization to ensure real time execution of any routine which is requested by the front end units. Figure 6-1 shows the flow diagram of the microprocessor operating routines, while Figure 6-2 shows the task allocation in real time operation.

## A. The microprocessor operating routine

When power is turned on, the microprocessor goes into a self memory test routine and ensures that enough RAM area is available, whereupon it sets up communication buffers, data storage area , stack area , variable locations, communication formats and timer modes. Once initialization is completed and the memory test result is sent back to the host computer it enters the interrupt driven mode. The interrupt sources are the A/D serial communication receiver and transmitter register, the D/A serial communication transmitter register, the AC load control serial communication receiver and transmitter register, the host

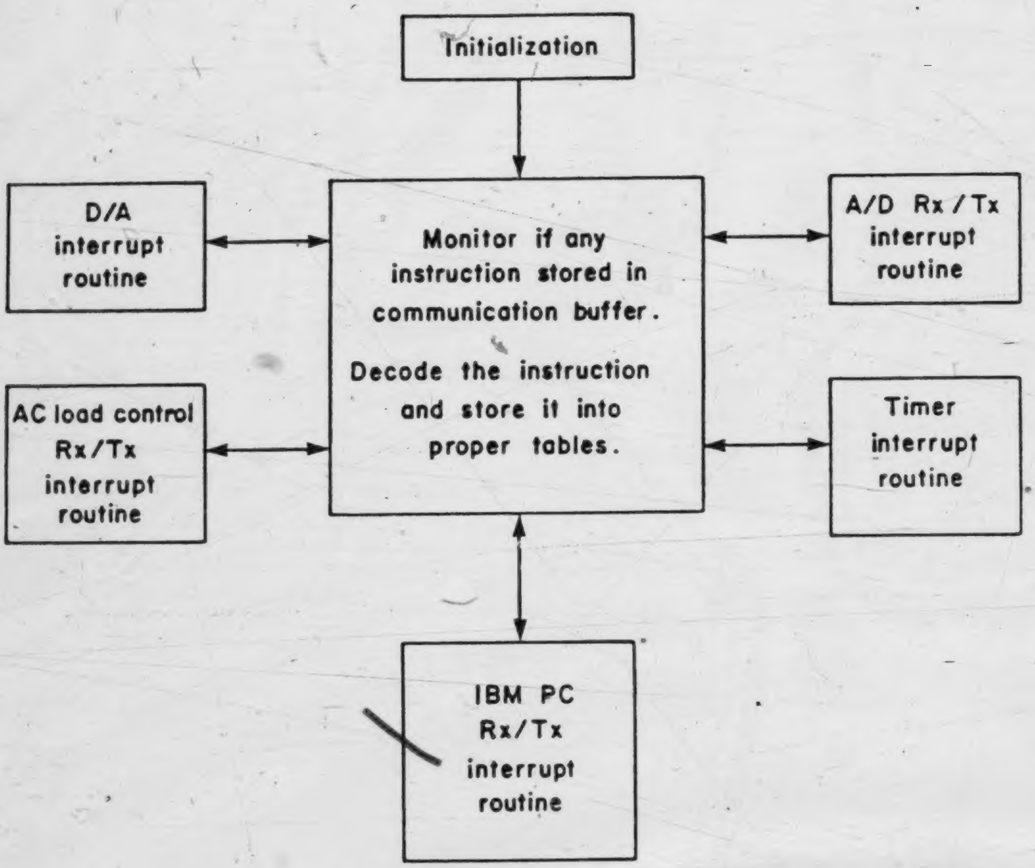

Initialization
D/A interrupt routine
Monitor if any instruction stored in communication buffer.
Decode the instruction and store it into proper tables.
A/D Rx / Tx interrupt routine
AC load control Rx/Tx interrupt routine
Timer interrupt routine
IBM PC Rx/Tx interrupt routine

Figure 6-1. The flow diagram of slave system operation.

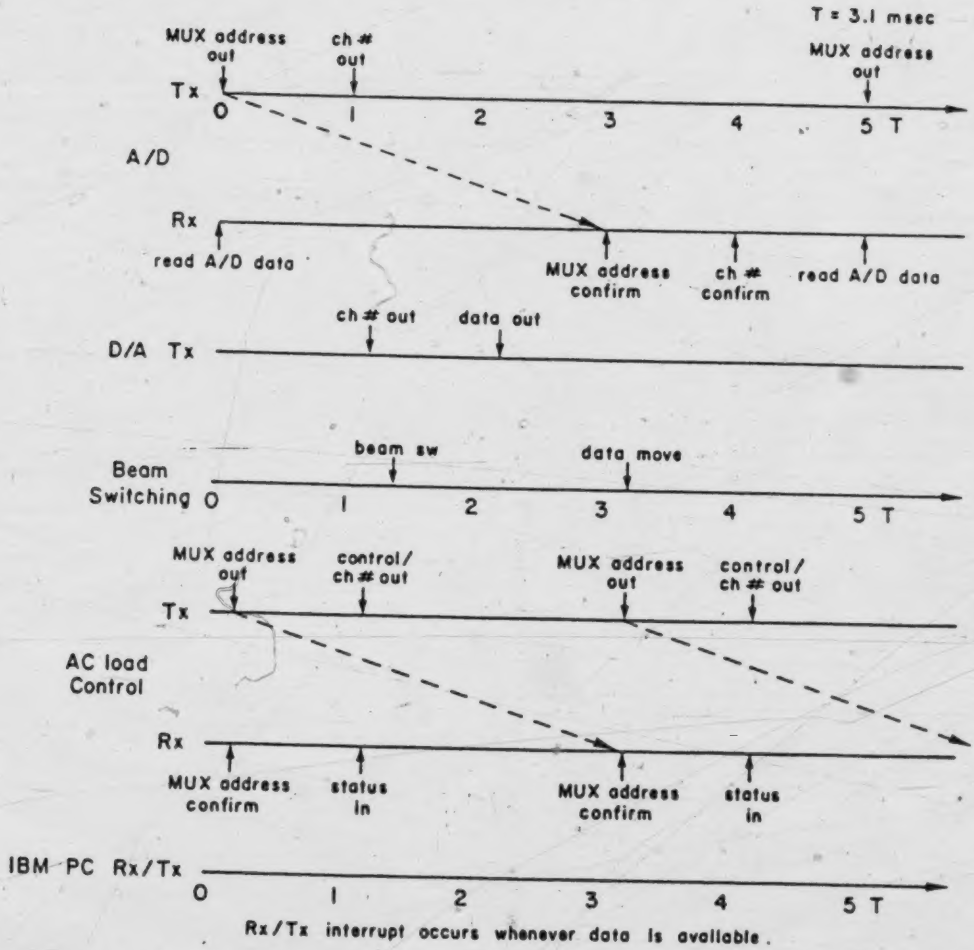

T = 3.1 msec
MUX address out
ch # out
MUX address out
Tx
0
1
2
3
4
5 T
A/D
Rx
read A/D data
MUX address confirm
ch # confirm
read A/D data
ch # out
data out
D/A Tx
beam sw
data move
Beam Switching
0
1
2
3
4
5 T
MUX address out
control/ ch # out
MUX address out
control/ ch # out
Tx
AC load Control
Rx
MUX address confirm
status in
MUX address confirm
status in
IBM PC Rx/Tx
0
1
2
3
4
5 T
Rx/Tx interrupt occurs whenever data is available.

Figure 6-2. The timing diagram of sequential ion beam.

computer interface serial communication receiver and transmitter registers, and the timer modules. The communication speed between host computer and slave computer is set at 2400 baud and all other serial communication is set at 3555 baud. The odd baud number of 3555 (455 K/128) is due to the use of an inexpensive 455 kHZ ceramic resonator as a clock oscillator for the front end units. The access time of the A/D unit is 15.5 msec. per channel and one full scan of 32 A/D channels takes 0.496 sec. A/D channels are continously and sequentially scanned and data is updated. The D/A access time is 6.2 msec. and the D/A is accessed only when the host computer sends out a new D/A setting value. AC load control access time per channel is 12.4 msec. and one full scan of 16 channels takes 0.1984 sec. AC load control units are continuously scanned and the load status is monitored and/or changed on instruction from the host computer. The AC load control command is normally read status only, but when a turn on/off instruction is given by the host computer the command is read status and turn on/off. The status report includes unit number, load on/off and error bit on/off. The ion beam energy change and beam switching is carried out by this routine once the host computer has supplied the beam switching timing schedule. Figure 6-3 shows the flow diagram of the beam switching and energy changing routine.

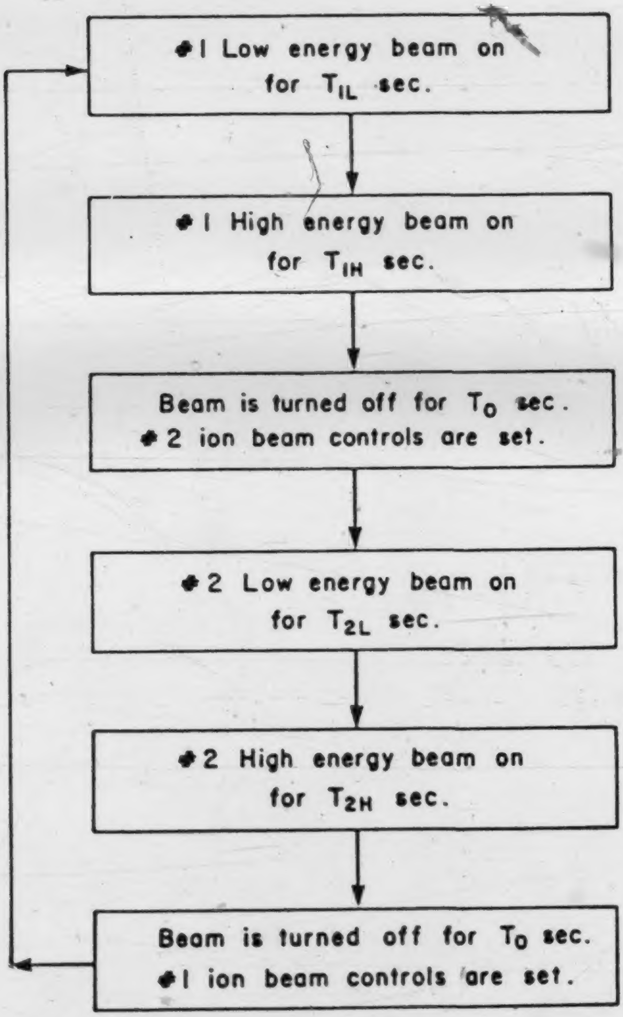

#1 Low energy beam on for $T_{1L}$ sec.
#1 High energy beam on for $T_{1H}$ sec.
Beam is turned off for $T_0$ sec. #2 ion beam controls are set.
#2 Low energy beam on for $T_{2L}$ sec.
#2 High energy beam on for $T_{2H}$ sec.
Beam is turned off for $T_0$ sec. #1 ion beam controls are set.

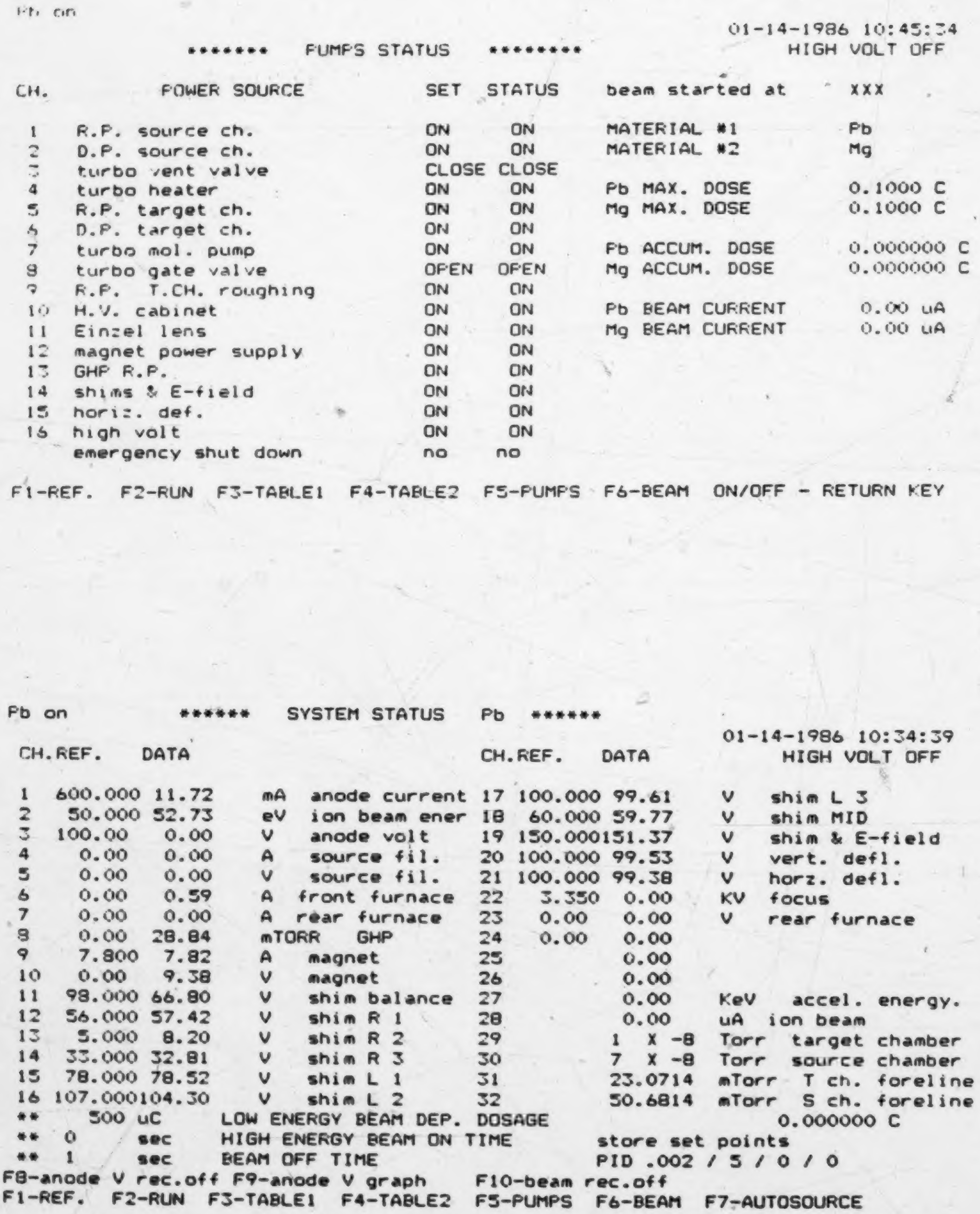
Figure 6-3. The flow diagram of ion beam switching routine.

### B. Start-up/Shut down and outgassing routine

The ion beam deposition system startup and shut down operation requires a series of strict sequential operations for pumps, valves and ionization gauges. For example, the foreline rotary pump must evacuate the chamber to a sufficiently low pressure before the diffusion pump heater can be switched on, to prevent oxidation of the diffusion pump oil. Such rules in the vacuum lines are supervised in this routine by monitoring pressures at several positions. When a new filament is installed in the ion source it has to be outgassed before being used as an electron source. The basic rule in outgassing this filament is that neither the filament nor ion source can be thermally shocked and pressures over $1 \times 10^{-5}$ torr should be avoided during the entire outgassing period. This rule is achieved by increasing the filament current slowly while monitoring the chamber pressure, taking about 12 hours with a new filament ( start at 5 Amp., finish at 15 Amp., with 0.2 Amp./15 min. current, increasing only when resulting pressure is below $1 \times 10^{-5}$ torr). When the system outgassing is finished, the master operating program is loaded and started.

### C. Master operating program

The master operating program provides an extensive information display while handling data storage files. It has 10 different screen displays which include (1)two different A/D and D/A data displays in color for two different ion species, (2)pumps and valves status display in color, (3)ion source data graphic display, (4)one 9 hour ion beam current vs. time graphic display and 6 different time region 1.5 hour ion beam vs. time graphic displays. The selection of these screens are via function keys on the keyboard. The program also provides D/A control set points, beam switching time schedule and AC load control commands (Figure 6-4). It sends out A/D data request commands at every sampling interval which is normally set at 0.5 sec. The slave computer is running as it is set when no host computer command is issued. Therefore the host computer can be isolated temporarily from the system while the slave is running. The system operational parameters are collected whenever ion beam current data collection is initialized. The collected data is stored temporarily in RAM while the master routine is running and is then dumped into a diskette when the master routine is terminated. For further analysis the data may be transferred from the IBM PC to the University of Alberta main frame computer, an Amdahl 5860.



```
Pb on
                                                         01-14-1986 10:45:34
              *******   PUMPS STATUS   ********              HIGH VOLT OFF

CH.          POWER SOURCE          SET  STATUS   beam started at    XXX

 1   R.P. source ch.               ON     ON     MATERIAL #1        Pb
 2   D.P. source ch.               ON     ON     MATERIAL #2        Mg
 3   turbo vent valve              CLOSE CLOSE
 4   turbo heater                  ON     ON     Pb MAX. DOSE       0.1000 C
 5   R.P. target ch.               ON     ON     Mg MAX. DOSE       0.1000 C
 6   D.P. target ch.               ON     ON
 7   turbo mol. pump               ON     ON     Pb ACCUM. DOSE     0.000000 C
 8   turbo gate valve              OPEN  OPEN    Mg ACCUM. DOSE     0.000000 C
 9   R.P.  T.CH. roughing          ON     ON
10   H.V. cabinet                  ON     ON     Pb BEAM CURRENT     0.00 uA
11   Einzel lens                   ON     ON     Mg BEAM CURRENT     0.00 uA
12   magnet power supply           ON     ON
13   GHP R.P.                      ON     ON
14   shims & E-field               ON     ON
15   horiz. def.                   ON     ON
16   high volt                     ON     ON
     emergency shut down           no    no

F1-REF.  F2-RUN  F3-TABLE1  F4-TABLE2  F5-PUMPS  F6-BEAM  ON/OFF - RETURN KEY
```

```
Pb on          ******   SYSTEM STATUS   Pb   ******
                                                         01-14-1986 10:34:39
 CH.REF.   DATA                          CH.REF.   DATA          HIGH VOLT OFF

 1  600.000 11.72    mA  anode current 17 100.000 99.61    V   shim L 3
 2   50.000 52.73    eV  ion beam ener 18  60.000 59.77    V   shim MID
 3  100.00   0.00    V   anode volt    19 150.000151.37    V   shim & E-field
 4    0.00   0.00    A   source fil.   20 100.000 99.53    V   vert. defl.
 5    0.00   0.00    V   source fil.   21 100.000 99.38    V   horz. defl.
 6    0.00   0.59    A  front furnace  22   3.350  0.00    KV  focus
 7    0.00   0.00    A  rear furnace   23   0.00   0.00    V   rear furnace
 8    0.00  28.84    mTORR  GHP        24   0.00   0.00
 9    7.800  7.82    A   magnet        25          0.00
10    0.00   9.38    V   magnet        26          0.00
11   98.000 66.80    V   shim balance  27          0.00    KeV   accel. energy.
12   56.000 57.42    V   shim R 1      28          0.00    uA  ion beam
13    5.000  8.20    V   shim R 2      29         1  X -8  Torr  target chamber
14   33.000 32.81    V   shim R 3      30         7  X -8  Torr  source chamber
15   78.000 78.52    V   shim L 1      31        23.0714  mTorr  T ch. foreline
16  107.000104.30    V   shim L 2      32        50.6814  mTorr  S ch. foreline
**     500 uC    LOW ENERGY BEAM DEP. DOSAGE                    0.000000 C
**   0      sec   HIGH ENERGY BEAM ON TIME       store set points
**   1      sec   BEAM OFF TIME                  PID .002 / 5 / 0 / 0
F8-anode V rec.off F9-anode V graph    F10-beam rec.off
F1-REF.  F2-RUN  F3-TABLE1  F4-TABLE2  F5-PUMPS  F6-BEAM  F7-AUTOSOURCE
```

Figure 6-4. The master operating system information display formats. AC load control status(top) and A/D and D/A data display(bottom).

# VII. Binary Alloy Thin Film Production and Analysis

## A. Introduction

Before starting the ion beam deposition of binary alloy films, a proper combination of material has to be selected and the ion source (previously loaded with charge elements) has to be outgassed to ensure efficient and lasting ion beam deposition. The outgassing has been carried out by the same computer system used for sequential ion beam deposition under a different software routine described in the previous chapter. Chapter VII covers the ion source preparation, source charge material selection, mass selectivity and system operational parameters used for Pb/Mg binary alloy deposition.

The major analytical technique used in this experiment is Rutherford backscattering spectroscopy (RBS) to analyze the composition of alloy films. A brief review of this technique is given in section F, followed by a detailed analysis of its application to this experiment. As a complement to RBS, scanning electron microscopy (SEM) and transmission electron microscopy (TEM) are used to evaluate the surface topography and the crystal structure of films. The results of RBS,SEM and TEM analysis are also covered by this chapter.

### B. Ion source preparation

A reliable, uninterrupted period of operation of the ion source is a key factor in a reliable ion beam system. The most common cause of failure with a hot cathode electron impact type ion source operating with a solid charge is the deterioration of the filament: in this case either the furnace filament and/or the source filament. The main cause of premature failure of either filament is a high discharge pressure in the ion source and/or excessive applied filament power. To maximize filament life time, a slow outgassing of both filaments before striking a plasma in the discharge chamber is considered essential. The outgassing process also reduces the partial pressure of undesired impurity elements and increases the portion of the desired element partial pressure in the discharge chamber. The higher the portion of the partial pressure of the desired species in the discharge chamber, the more ionization of that species becomes possible under constant discharge pressure, potential and current.

The material of the ion source housing is boron nitride. Although this is a machinable ceramic with an excellent high temperature rigidity, its resistivity falls as temperature rises. This resistivity change can be exacerbated by the presence of absorbed moisture with the result that some of the electrical current used to heat the filament is directed through the boron nitride. As much of the absorbed moisture as possible therefore must be removed by careful outgassing in the vacuum. A rapid degassing schedule can cause disastrous swelling of the boron nitride if the absorbed moisture undergoes a phase change to the vapour state when it is still trapped within the interstices of the ceramic.

In most cases during the present work, the source filament has failed before the furnace filament. A well outgassed ion source filament has lasted for 100 hours of normal operation, depending on the charge element and the ion source operational parameters.

Figures 7-1 and 7-2 show the ion source chamber pressure change as a function of two different rates of rise of filament current during the outgassing process. Neither of these rates of rise caused excessive pressure build up in the source chamber, under the programmed constraint that the source chamber vacuum level must be maintained below $1\times10^{-5}$ torr during the outgassing period. With proper outgassing and a low discharge pressure, the gradual deterioration of the source filament is mainly caused by ion bombardment. Ions leaving the plasma region in the ion source flow towards the source filament. The kinetic energy of these bombarding ions is almost equivalent to the discharge potential applied between anode and source filament.

It has been noticed here that the lifetime of a source filament varies depending on how the source filament dc power supply is connected to the source filament. Figure 7-3 shows the source filament, the discharge power supply

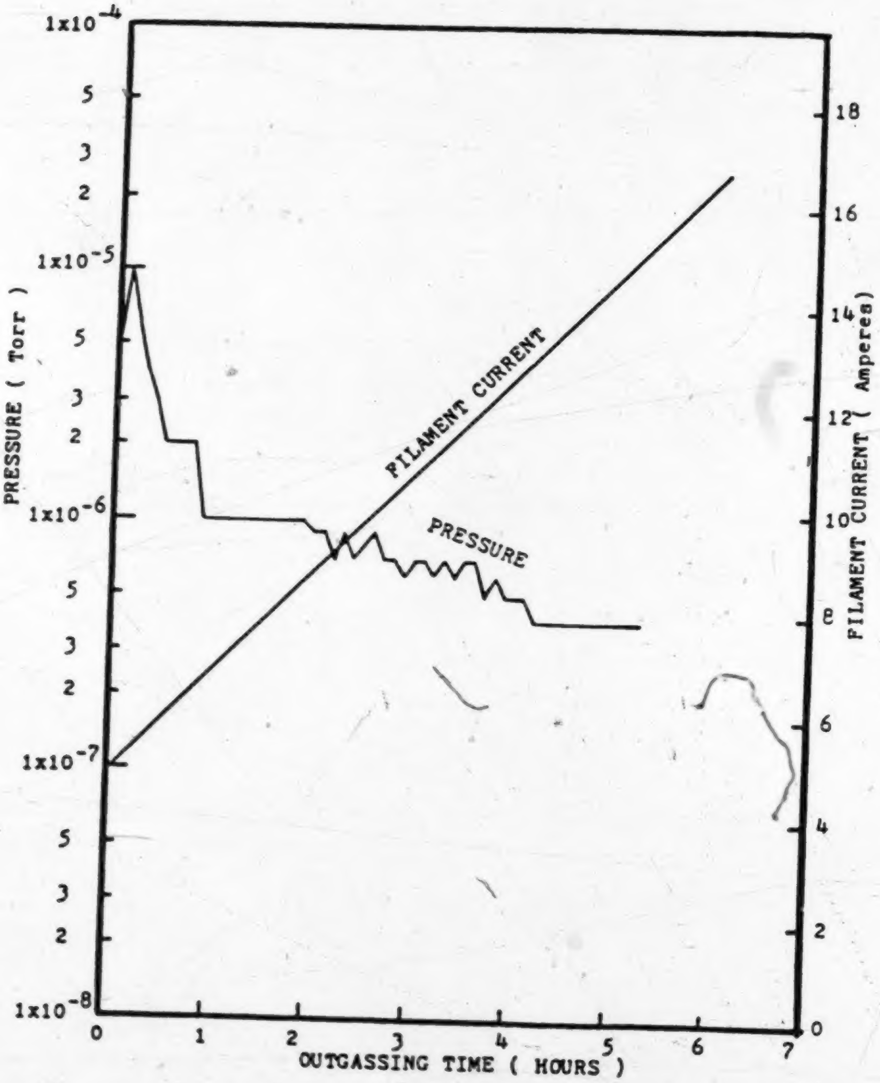


Figure 7-1. Ion source chamber pressure vs. ion source outgassing speed -1
(filament current increase: 0.5 amp./15 min.)

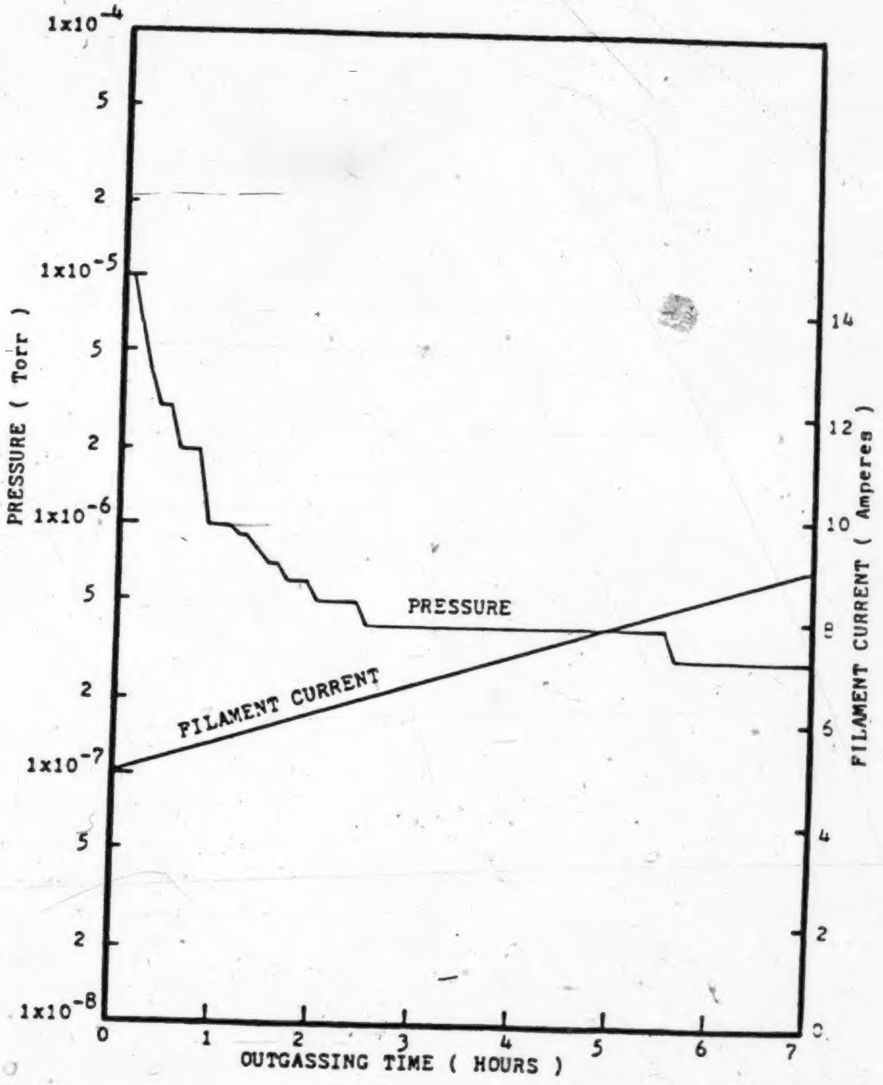


Figure 7-2. Ion source chamber pressure vs. ion source outgassing speed -2
(filament current increase: 0.3 amp./15min.)

Table 7-1 **Ion Source Filament Specifications**

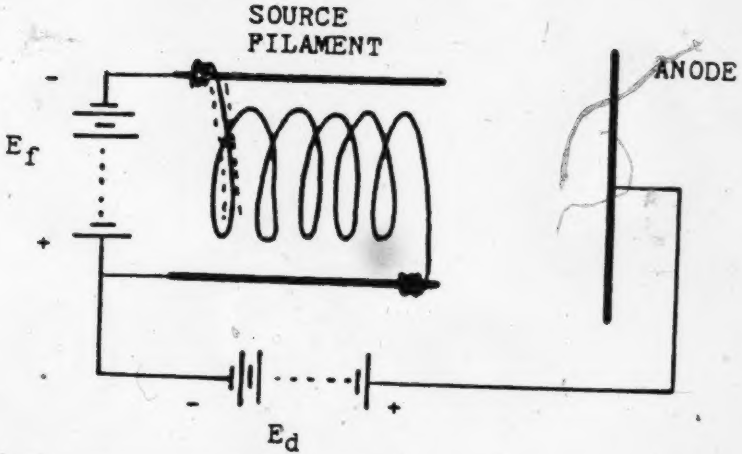
| | discharge fil. | furnace fil.(#1,#2) |
|---|---|---|
| material | 0.02" dia. W wire | 0.02" dia. W wire |
| length | 7.0 inches | 5.0 inches |
| operating current | 18 Amp. | 20, 15 Amp. |
| temperature(*1) | 2500 °K | 2600, 2200 °K |
| electron emission | 1050 mA (150mA/in) | |

* Filament temperature and saturated electron emission did not include the effect of ion bombardment.

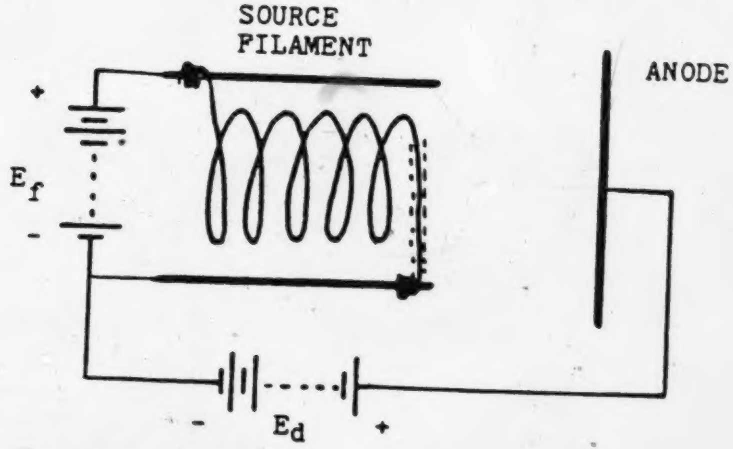
connection and the filament burn out point in each connection. The connection mode of Fig. 7-3a yields almost double the filament lifetime of that shown in Fig. 7-3b. Ions hitting the negative end of the filament would have a higher energy than those hitting the positive end of the filament; it would appear logical then that the negative end of the filament must be placed further away from the plasma, to minimize a higher erosion rate from positive ion bombardment.

### C. Ion source charge material selection

Due to the operating temperature limit of the ion source furnaces, the proper combination of materials has to be selected with regard to their vapor pressure and


SOURCE
FILAMENT
ANODE
-
$E_f$
+
-
$E_d$
+

a) $E_f$ connection-1
failure area at bottom of source filament(dotted area).
longer filament life time.


SOURCE
FILAMENT
ANODE
+
$E_f$
-
-
$E_d$
+

b) $E_f$ connection-2
failure area at top of source filament(dotted area).

Figure 7-3. Source filament connection and failure spot.

ionization characteristics. The furnace temperature can be maintained up to 1800 °K without rapid deterioration of furnace filaments. Figure 7-4 shows the vapor pressure characteristics of prospective source materials. When two elements with different vapor pressure are charged in the ion source furnaces, maintaining optimum total pressure with equal partial pressure of each element in the discharge chamber is essential to keep the ionization of both species high. Therefore two separate furnaces with separate filaments are used to maintain adequate vapor pressure of each element. A lower vapor pressure element (high temperature element) is usually stored in the front furnace because it was found difficult to maintain the front furnace temperature below a certain level even with the furnace filament turned off after the plasma is turned on. In the case of Pb and Mg binary operation, Pb is charged in the front and Mg is charged in the rear furnace. Other succesful binary combinations observed are Al and Zn, Mg and Zn, Al and Pb, and Mg and Sn.

### **D. Ion mass selection and focusing(Colutron E X B mass filter)**

Figure 7-5 shows the magnet current selection chart with different E field power supply settings. In a binary alloy deposition experiment, the E field power supply has been set to 150 Volts. With this setting of E field, a reasonably high mass element such as Pb is accommodated well

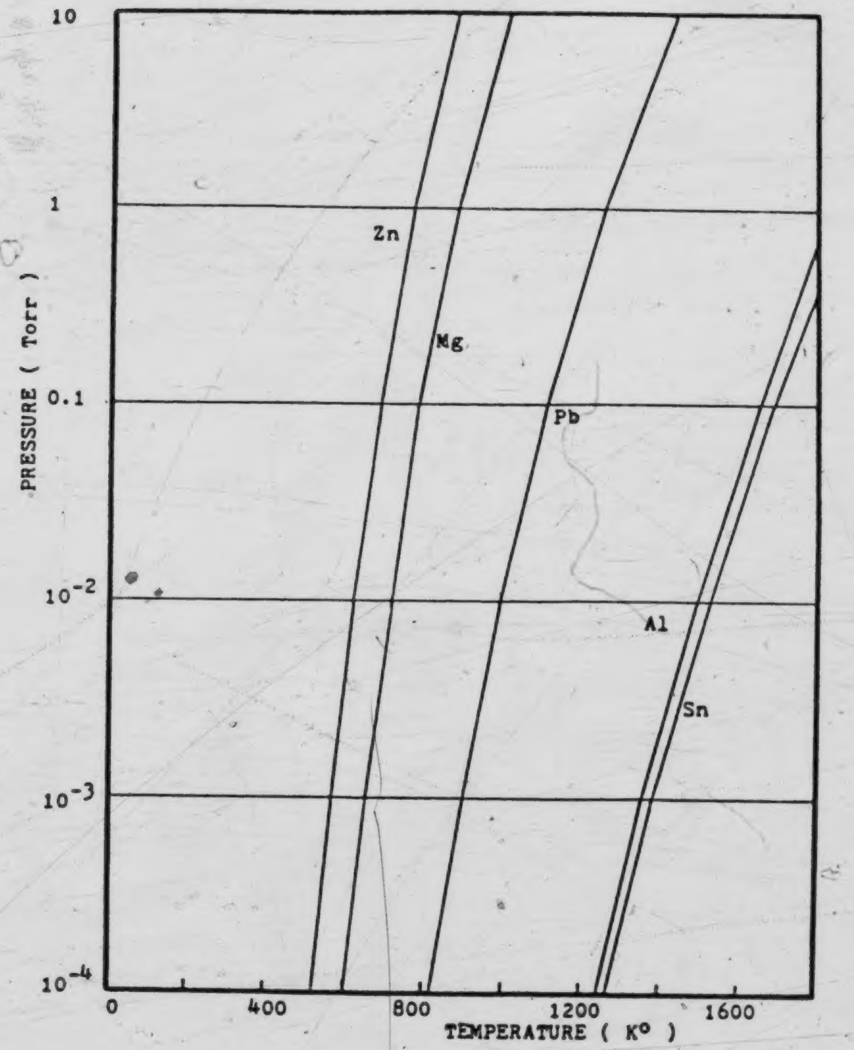


Figure 7-4. Vapor pressure characteristics of prospective source material(*2).

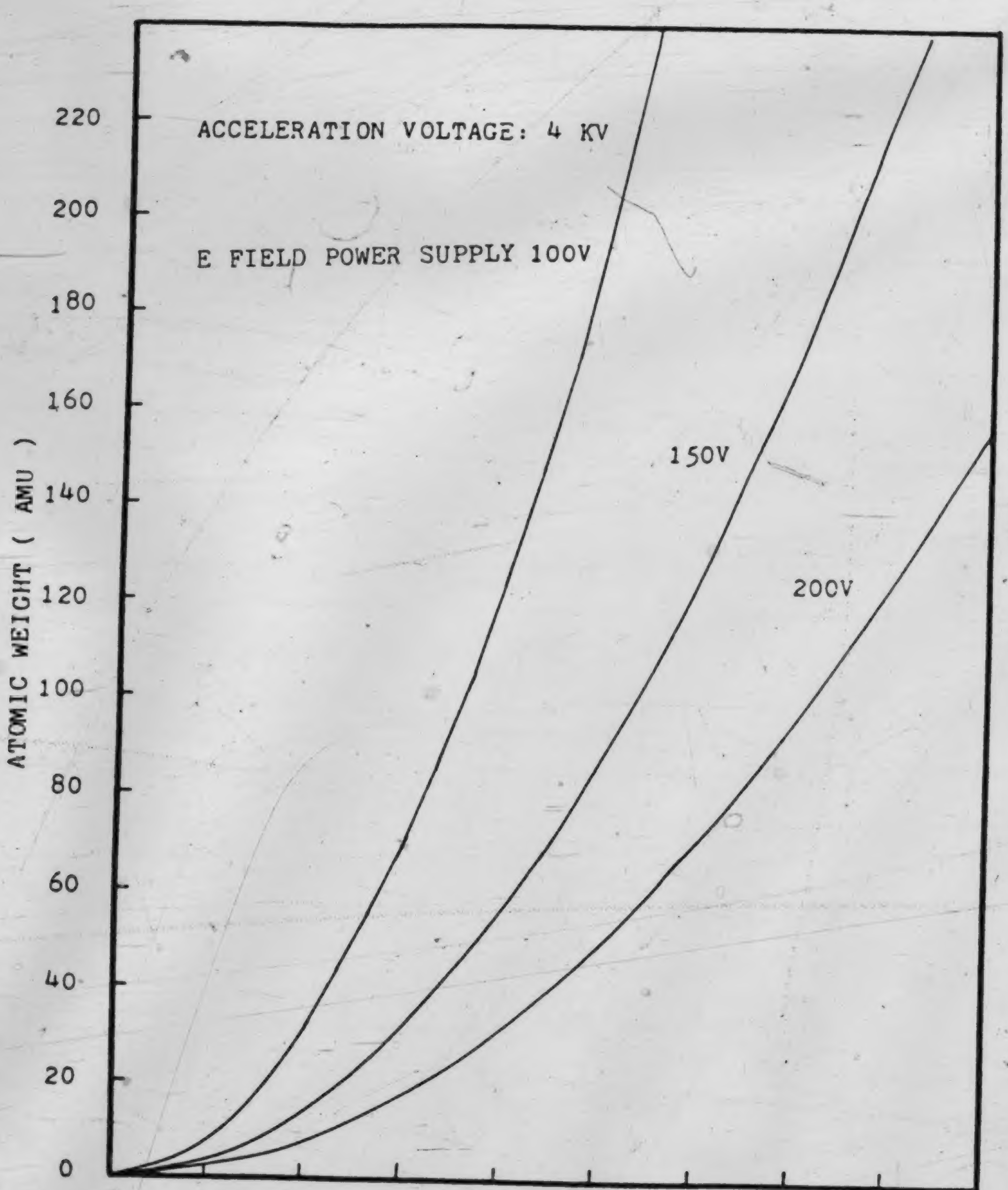


Figure 7-5. Velocity filter magnet current vs. mass.

below the magnet current limit of 10 Amperes. The mass resolution of this system is given by(*3),

$$M/\Delta M = alE(4VD)^{-1} \text{ ------ } (7\text{-}1)$$

where

a : the length of magnet

l : drift distance(from the center of magnet to target)

E : E field (V/m)

V : acceleration potential

D : the dispersion between mass M and M-ΔM

Applying a=15 cm, l=25 cm, $E=8.3\times10^3$ V/m, D=5 mm, and V=4 kV, the mass resolution of this binary alloy deposition system is given by,

$$M/\Delta M = 4.0 \text{ -------- } (7\text{-}2)$$

By increasing the drift distance l, the mass resolution can be increased but the space charge expansion in the long drift section reduces the intensity of ions arriving at the target. Applying the maximum allowable E field of 12500 V/m can improve the mass resolution, but the maximum mass range drops to near 120 AMU. When the involved element masses are below 120 AMU, use of the maximum E field results in an increase in mass resolution by a factor of 1.5 from that given by equation 7-2.

### E. Pb/Mg binary alloy deposition parameters

The following parameter settings are typical for Pb/Mg binary alloy deposition.

1. parameters common to both elements.
    - a. discharge current : 600 mA
    - b. discharge potential : 100 Volts
    - c. source filament power : 18 Amp. x 12 Volt
    - d. acceleration potential : 4 kV
    - e. vertical deflection : 100 Volt
    - f. horizontal deflection : 150 Volt
    - g. E field power supply : 150 Volt
    - h. target chamber pressure : $1 \times 10^{-8}$ Torr
    - i. beam transport chamber pressure : $1 \times 10^{-7}$ Torr
    - j. ion source PID control : $K=0.002, T_i=5T, T_d=0.2T, T=0.5$ sec.
    - k. ion beam deposition energy : 50 eV
    - l. decelerator lens system : 90° conical decelerator, 1.0 inch high, 0.25 inch diameter hole on the target side.
    - m. target mask : a stainless steel mask with 3/16 inch diameter hole, target and target mask are electrically isolated.
    - n. target : vitreous carbon, 5/8 inch diameter, 1/8 inch thick for RBS and SEM specimen.

      target for TEM specimen : NaCl covered by thin carbon film.

2. non-common parameters(Pb/Mg)
    - a. magnet current : 7.9 / 2.4 Amperes
    - b. furnace filament powers : 13 Amp x 8 Volt/10 Amp x 5 Volt
    - c. shim controls(Volt) : balance 98/137, middle 0/76, R1 53/45, R2 32/25, R3 63/37, L1 85/89, L2 108/112, L3 126/140
    - d. focusing : 3.25 / 3.30 kV
    - e. ion beam current : 5/8 μA
    - f. deposition switching batch dosage : 1000 μC/1000 μC (in case of 50/50 % deposition)
    - g. ion beam high/low energy switching : energy range 0 - 300 eV, switching batch dosage variable.
    - h. ion bombardment time : 4 keV beam, bombarding time variable
    - i. ion beam blocking time between beam switching : normally 1 - 2 sec., variable

### F. Pb/Mg alloy thin film analysis by RBS

When an energetic particle beam irradiates a target, a fraction of the incident particles is scattered back from the target by Coulomb repulsion of the atomic nuclei (Rutherford scattering). The application of Rutherford backscattering to thin film analysis was begun in the early 1970's by Chu et. al(*4,5,6,7). One outstanding feature of this technique is the capability of depth resolution as well as mass, density and composition resolution. The mass resolution arises through the energy loss incurred by the small fraction of incident ions which are backscattered elastically by the Coulomb repulsion of atomic nuclei. The energy of the incident ion after backscattering is smaller than its initial energy $E_0$ by an amount which depends both on the scattering angle and the mass of the incident ion and a target atom. When the backscattering angle, $\theta$ and the incident ion energy, $E_0$ and mass, m are given, an unknown mass M of target atom can be identified by measuring the backscattered particle energy E (equation 7-3, Figure 7-6).

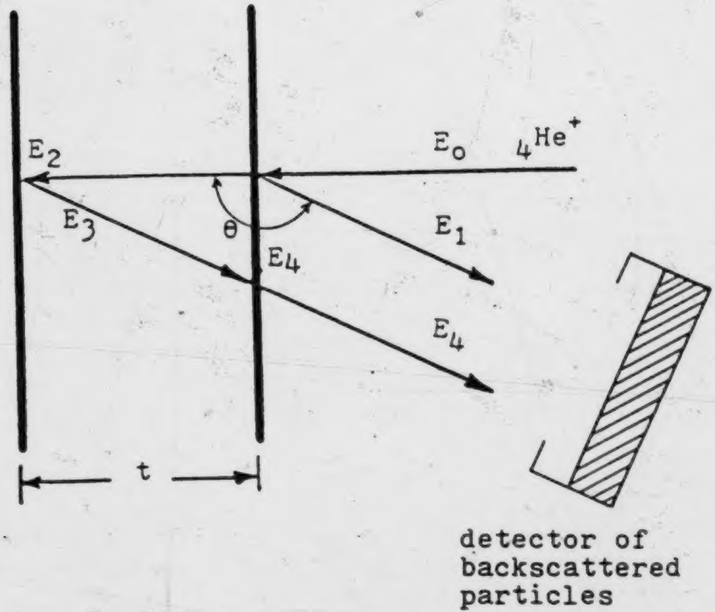
$$E=K_m E_0 \text{ ------------ } (7\text{-}3)$$

where

the kinematic recoil factor $K_m$ is given by :

$$K_m=\{[m \cos\theta + (M^2-m^2\sin^2\theta)^{1/2}]/(m+M)\}^2$$

Most of the incident particles undergo small-angle deflections, penetrating deeper within the target. In the process of penetration, the incident particles lose energy. The backscattered energy of those particles that re-emerge from underneath the surface after undergoing a large angle collision is smaller than the energy from those particles backscattered from the surface, because of their small-angle interactions with target atoms. The energy loss difference $\Delta E$ between the particles backscattered from the target surface and from depth t under the surface is given by(*9,10),


E2
E0
4He+
E3
θ
E1
E4
E4
t
detector of backscattered particles

$E_1=K_mE_0$

$E_2=E_0-\Delta E_1$

$E_3=K_mE_2$

$E_4=E_3-\Delta E_2$

$\Delta E_1=\epsilon_1 Nt$

$\Delta E_2=\epsilon_1 Nt/\cos\theta$

Figure 7-6. Schematic representation of the backscattered particle energy from a thin slab of target.

$\Delta E=[S]\ t$ --------------------- (7-4)

where

$[S]=Km\ dE/dx)_i+1/\cos\theta\ dE/dx)_t$

[S] : backscattering energy loss factor

$dE/dx)_i$ : target atom stopping power at the energy of an inbound particle

$dE/dx)_t$ : target atom stopping power at the energy of an outbound particle after a wide angle collision at depth t.

Equation 7-4 can be rewritten using the stopping cross section $\epsilon$(*9,10).

$\Delta E=[\epsilon]Nt$ ------------ (7-5)

where

$[\epsilon]=K_m\epsilon_i + \epsilon_t/\cos\theta$ : stopping cross section factor

$\epsilon_i$ : $\epsilon$ at inbound particle energy

$\epsilon_t$ : $\epsilon$ at outbound particle energy

N : atomic density of target

Data of stopping cross sections from various elements are available for a wide range of $_4He^+$ energy(*8,9). From equation 7-5, with given energy loss parameter data of target atoms, the thickness of a homogeneous film can be determined by measuring $\Delta E$, the energy difference between particles bacscattered from the surface and the one backscattered from the other end of the film.

When a number of incident helium particles irradiate a target, only a small fraction of them are backscattered. The possibility of an incident particle being backscattered when passing through the target material depends on the atomic density of the target and the scattering cross section of the target atom. The backscattering yield A is given by(*9,10),

$$A=(\Omega QN/\cos\theta)\int_0^t \sigma(E)\,dx \text{ --------------} (7\text{-}6)$$

where

$\Omega$ : solid angle of detector

Q : particle irradiation dosage

$\sigma(E)$ : scattering cross section at energy E

t : film thickness

An unknown target atomic density can be derived from equation 7-6 by integrating the backscattered particle counts when other parameters are given. The detector solid angle $\Omega$ and the backscattered angle $\theta$ can be obtained by measuring detector and target geometry and the position where the incident beam hits the target. The irradiation dosage Q is measured by integrating target current.

From equation 7-6, if the geometry of the Rutherford backscattering target chamber is not changed and the same amount of probing beam dosage is used, the backscattered particle count at the detector is directly proportional to the number of atoms in the target and the scattering cross section. When the backscattering angle $\theta$ is close to 180° and m<<M, then a special case of scattering cross section is given by(*9,10),

$d\sigma/d\Omega \approx [Z_1 Z_2 \, e^2/(4E)]^2$ ----------- (7-7)

where

$Z_1, Z_2$ : atomic number of incident beam and target

$E$ : incident beam energy

$e$ : electronic charge

From equation 7-6 and 7-7, the backscattering yield ratio from a homogeneous thin composite target becomes(*9,10),

$A_1/A_2 = N_1 \, N_2^{-1} \, (Z_1/Z_2)^2$ ----------------- (7-8)

where

subscript 1,2 : element 1,2 in composite target.

In reality, a backscattered helium particle strikes a silicon surface barrier detector whose resistivity changes by an amount that is related to the energy of the particle. The resistivity change is translated into a particle count as a function of energy. This cumulative data is stored in bins of a multichannel analyzer system as particle counts per bin(channel). Because the energy width of each bin(channel) is identical, the height of the channel can be used in similar way as the total area of an energy spectrum is used in defining the composition ratio of a homogeneous composite target.

From the definition of the stopping cross section factor, the energy width $W_1$, $W_2$ from the spectrum of element 1 and 2 of composite target is given by,

$$W_1=[\epsilon]_1 Nt$$

$$W_2=[\epsilon]_2 Nt \text{ ---------- } (7\text{-}9)$$

When the channel energy width $\Delta E$ is specified, the number of channels for each spectrum, $n_1$ and $n_2$ is given by,

$$n_1=W_1/\Delta E=[\epsilon]_1 Nt/\Delta E$$

$$n_2=W_2/\Delta E=[\epsilon]_2 Nt/\Delta E \text{ ------ } (7\text{-}10)$$

The spectrum width ratio is given by the ratio of stopping cross section factor. The height of spectrum can be defined from total area and the number of channels the spectrum occupies.

The spectrum height is given by,

$$H_{m1}=A_1/n_1=A_1\Delta E/([\epsilon]_1 Nt)$$

$$H_{m2}=A_2/n_2=A_2\Delta E/([\epsilon]_2 Nt) \text{ ------ } (7\text{-}11)$$

From equation 7-8 and 7-11, the spectrum height ratio is given by,

$$H_{m1}/H_{m2}=N_1/N_2(Z_1/Z_2)^2([\epsilon_1]/[\epsilon_2]) \text{ -------------- } (7\text{-}12)$$

From equation 7-12, the composition ratio can be solved by comparing the height of two spectra from the same depth within the target, provided that the target stopping cross section factor and target atomic numbers are known. The stopping cross section factor $[\epsilon]_i$ is a function of composition ratio and the energy of the incident particle. Therefore if the composition ratio is not known, the correct $[\epsilon]_i$ is not available. An iterative method can be used in a machine calculation to solve equation 7-12, by making an initial assumption of a common stopping cross section factor for all elements in the composite. The error of this initial assumtion is usually less than $(K_{m1}-K_{m1})/(1+K_{m2})$ when $K_{m1} >> K_{m2}$. In case of a Pb and Mg composite material, the initial error is 27% at worst and decreases with continued iterations.

The depth profile of a composite material can be obtained by implementing equation 7-12 with a computer. But the backscattering experiment instrumentation has a finite energy resolution, which is dependent on the resolution of the Si surface detector and of the signal amplifiers and data acquisition system. Because of the statistical nature of the energy loss of the incident probing particle, the energy of backscattered particles has a Gaussian distribution (energy straggling) which is a function of the target atomic number as well as the backscattered energy; the deeper they travel before being backscattered in the target, the larger is the energy straggling. The noise present in the electronics system also contributes to the poor signal to noise ratio in the low yield of the backscattered energy spectrum. When the target contains two similar mass elements or a film that is too thick, the resulting spectra overlap in yield. Separation of the spectra becomes necessary before doing any quantitative analysis. Without giving proper consideration to the above added effects, quantitative depth profiling would not produce a real picture of a target profile.

As an alternative method in identifying a composite target which is assumed homogeneous, a comparison method has been developed here. First, a number of spectra of given composites are synthesized and then the spectrum from experiment was compared with the synthesized ones.

When synthesizing spectra from composite targets, correct data for the stopping cross sections and atomic densities for the composite have to be provided. For the calculation of composite stopping cross section, Bragg's rule is applied(*11) ;

$$\epsilon_{12}=k_1\epsilon_1+k_2\epsilon_2 \text{ ------------ } (7\text{-}13)$$

where

$\epsilon_{12}$ : composite stopping cross section

$k_1, k_2$ : composition ratio, $k_1+k_2=1$

The atomic density of a composite N' is given by(*12),

$$N'=1/(k_1/N_1 + k_2/N_2) \text{ ------ } (7\text{-}14)$$

where

$N_1, N_2$ : atomic density of element 1 and 2 respectively.

If a significant chemical reaction is likely between element 1 and 2 when they produce a composite, equation 7-14 becomes invalid. The above equation is derived from the initial assumption of an unchanged unit atomic volume of each element even after they are mixed together to make a composite. In calculating the atomic density of the composite of Pb,Mg and O, the density of MgO is used for Mg and O because it is known that pure Mg turns to MgO whenever Mg is placed in an oxygen environment. Table 7-2 shows the ratios of spectrum height, width and area for different composition ratios which have been considered in alloy film production.

Figure 7-7 shows the instrumentation layout used for RBS data collection in this thesis. A backscattering angle of 170° is employed with an ORTEC Si surface barrier detector. The detector solid angle is measured as 2.8 x $10^{-3}$ Sr and detector bias of 120 Volt is applied. From Si detector parameter nomograph(*13), the detector produces about 100$\mu$m thick depletion layer at this bias potential and 2.0 MeV $\alpha$ particles are completely blocked in this layer.

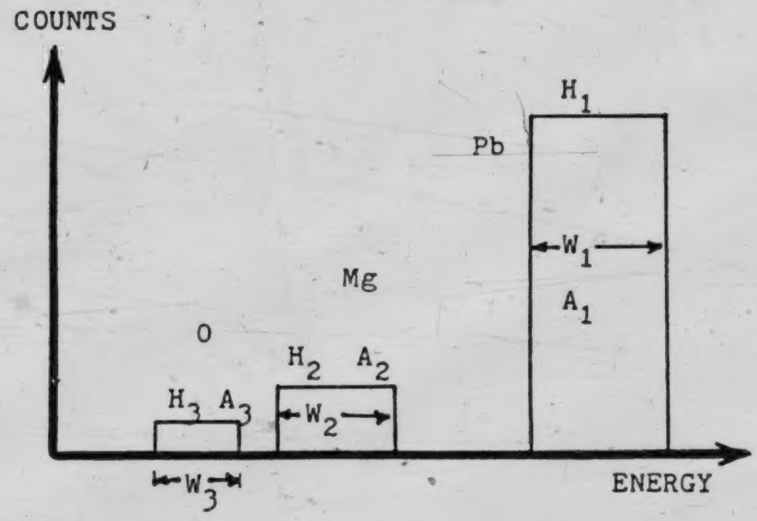
**a) Pb/Mg 25/75% deposition**

Figure 7-8 shows the RBS spectrum from a thin film deposited by 50 eV $Pb^+$ and $Mg^+$ beam, switched sequentially with a switching batch dosage of 200$\mu$C and 600$\mu$C respectively. The initial ion beam current of 3.3$\mu$A of $Pb^+$ and 7.3$\mu$A of $Mg^+$ were obtained and the total deposited dosages are 0.01C and 0.03C each.

The area, height and width ratios were measured from the spectra and compared with the theoretical values obtained from analysis of ideal spectra. The comparisons are given by,

Table 7-2

**The area, height and width ratio of synthesized RBS spectra of different composites of Pb/Mg/O.**



| composite<br>(Pb:Mg:O) | area<br>$A_1:A_2:A_3$ | height<br>$H_1:H_2:H_3$ | width<br>$W_1:W_2:W_3$ |
|---|---|---|---|
| 1:1:0 | 46.7:1:0 | 40.1:1:0 | 1.16:1:0 |
| 1:1:1 | 46.7:1:0.44 | 40.9:1:0.48 | 1.14:1:0.92 |
| 3:1:1 | 140:1:0 | 119.3:1:0 | 1.17:1:0 |
| 3:1:1 | 140:1:0.44 | 120.1:1:0.91 | 1.16:1:0.91 |
| 1:3:0 | 15.6:1:0 | 13.6:1:0 | 1.15:1:0.93 |
| 1:3:3 | 15.6:1:0.44 | 13.8:1:0.48 | 1.13:1:0.93 |
| 1:2:0 | 23.3:1:0 | 20.5:1:0 | 1.16:1:0 |
| 1:2:2 | 23.3:1:0.44 | 20.5:1:0.48 | 1.13:1:0.92 |
| 2:1:1 | 93.4:1:0.44 | 80.5:1:0.48 | 1.16:1:0.91 |

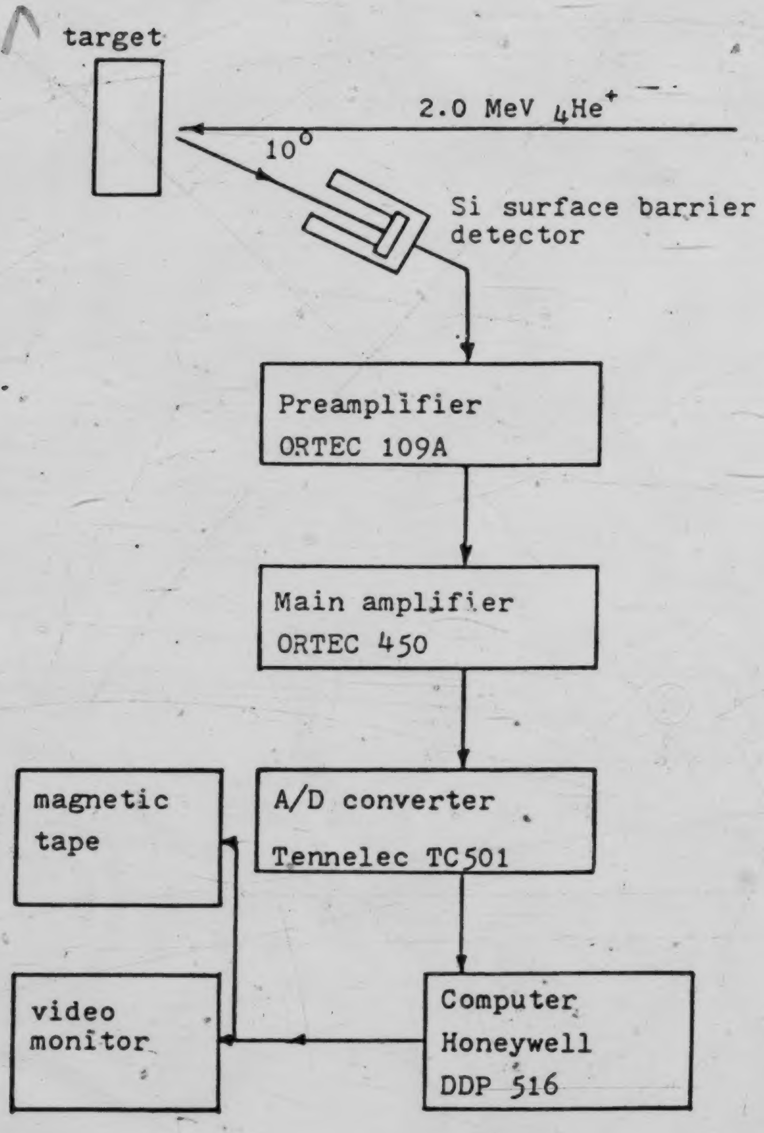

target
2.0 MeV $_4He^+$
10°
Si surface barrier detector
Preamplifier ORTEC 109A
Main amplifier ORTEC 450
A/D converter Tennelec TC501
magnetic tape
video monitor
Computer Honeywell DDP 516

Figure 7-7. The block diagram of RBS data collection instrumentation.

* ratio sequence : Pb : Mg : O

* theoretical values from a composite of 1:3:3(Pb:Mg:O) in parenthesis

- area ratio 15.6:1:0.5 (15.6:1:0.44)
- height ratio 13.6:1:0.57 (13.8:1:0.48)
- width ratio 1:1:0.8 (1.13:1:0.93)

* film thickness : 3200 Å

The film deposited with ion beam dosage ratio of 1:3(Pb:Mg) shows the RBS spectrum equivalent to a composite with 1:3:3(Pb:Mg:O). The oxygen is considered to be introduced to the magnesium after deposition. The probable periods of the oxygen introduction to the film are during the target removal from ion beam deposition system, the transport to RBS laboratory and mounting the film onto RBS target holder.

**b) Pb/Mg 50/50 % deposition.**

Figures 7-9 and 7-11 show the spectra from thin films produced by 50 eV $Pb^+/Mg^+$ ion beam deposition with beam switching batch dosage of 400μC/400μC (Fig. 7-10) and 1000μC/1000μC (Fig. 7-11). The total deposition dosages are 0.02C/0.02C(Fig. 7-10) and 0.025C/0.025C(Fig. 7-11). The comparison of spectrum data with theoretical values are ;

*ratio sequence ; Pb:Mg:O

*Figure 7-9 data given first followed by Fig. 7-11 data. The theoretical values from a composite of 1:1:1(Pb:Mg:O) in parenthesis.

- area ratio 48.9:1:0.48, 47.7:1:0.49 (46.7:1:0.44)
- height ratio 37.5:1:0.56, 37.9:1:0.47 (40.9:1:0.48)
- width ratio 1.1:1:0.9, 1.11:1:1 (1.14:1:0.92)

As before, the spectrum shows that the quantity of oxygen is identical with that of magnesium.

**c) Pb/Mg 75/25 % deposition.**

Figure 7-11 shows the RBS spectrum from a thin film which was produced by 50eV $Pb^+/Mg^+$ ion beam deposition with beam switching deposition batch dosage of 600μC/200μC. No visible sign of Mg nor O peak is observed from the spectra. As described in the backscattering yield ratio equation (equation 7-6): when a low mass element contributes only a small fraction of material to a composite, while the majority is made up from a high mass element, the backscattering yield from the low mass element is extremely small. In this event, the instrumentation noise produces a higher signal than this low backscattered data and the identification of the low yield backscattering signal becomes extremely diffcult. The theoretical value for a composite of 3:1:1(Pb:Mg:O) is given as 120:1:0.48 in Table 7-2. The spectrum did not have enough resolution to distinguish signal from noise in this case.

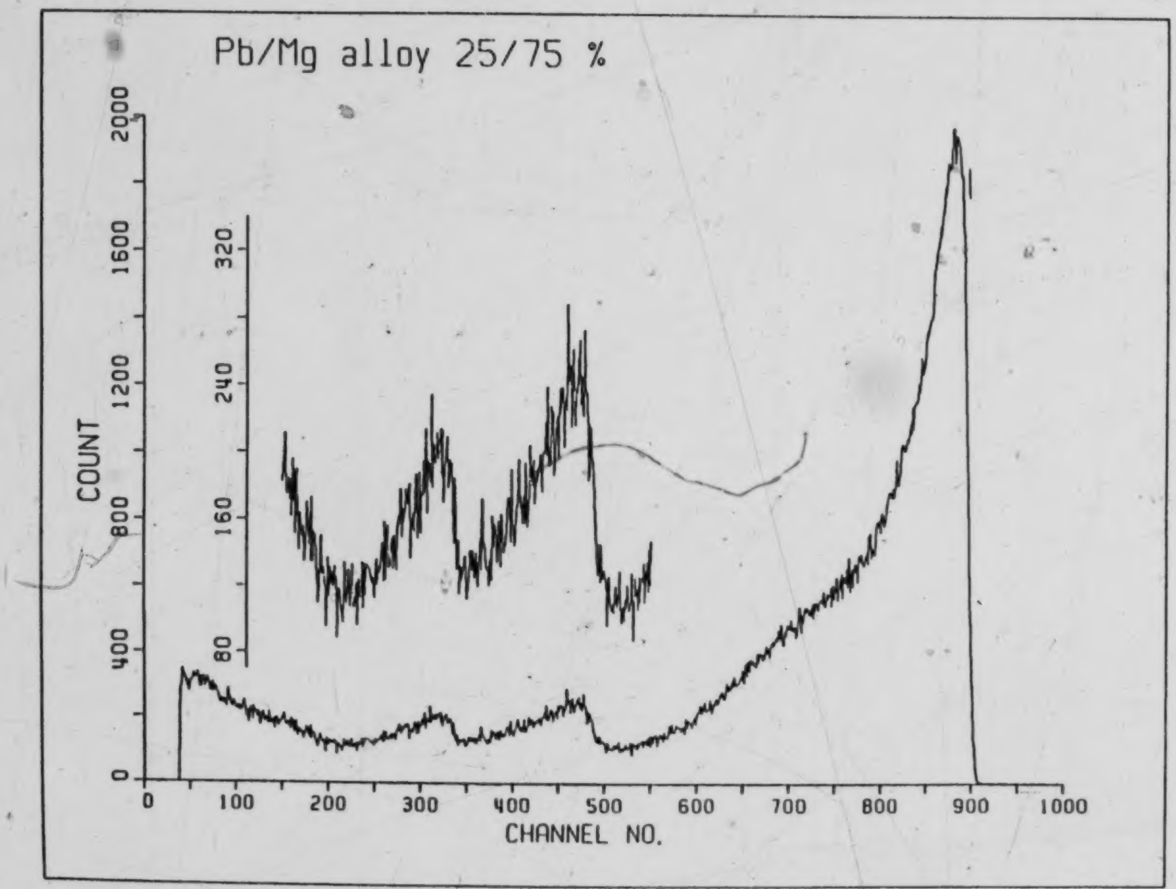


Figure 7-8. 2.0 MeV $^{4}He^{+}$ RBS spectrum from Pb/Mg alloy film deposited with 25/75(Pb/Mg) ion beam deposition dosage ratio.

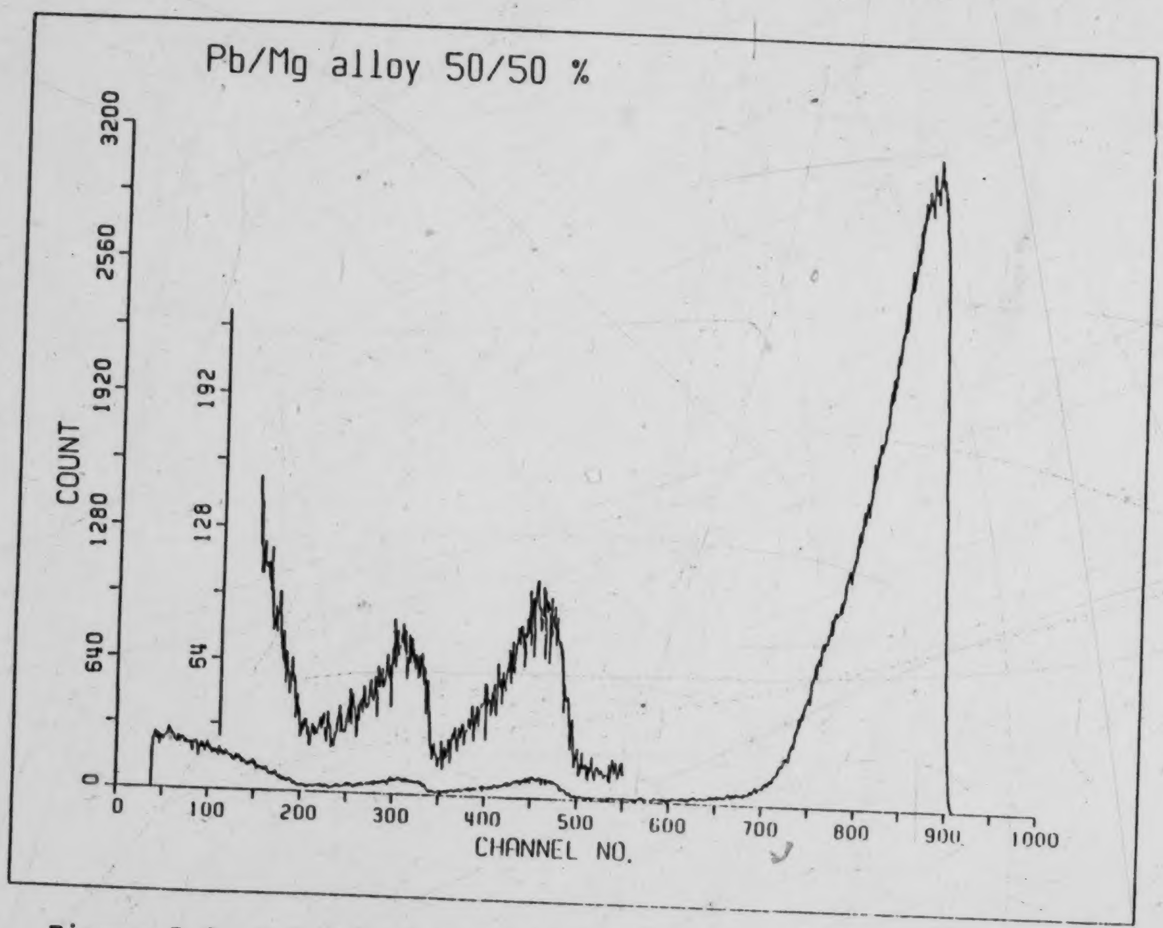


Figure 7-9. 2.0 MeV ${}_{4}He^{+}$ RBS spectrum from Pb/Mg alloy film deposited with 50/50(Pb/Mg) ion beam deposition dosage ratio.-1

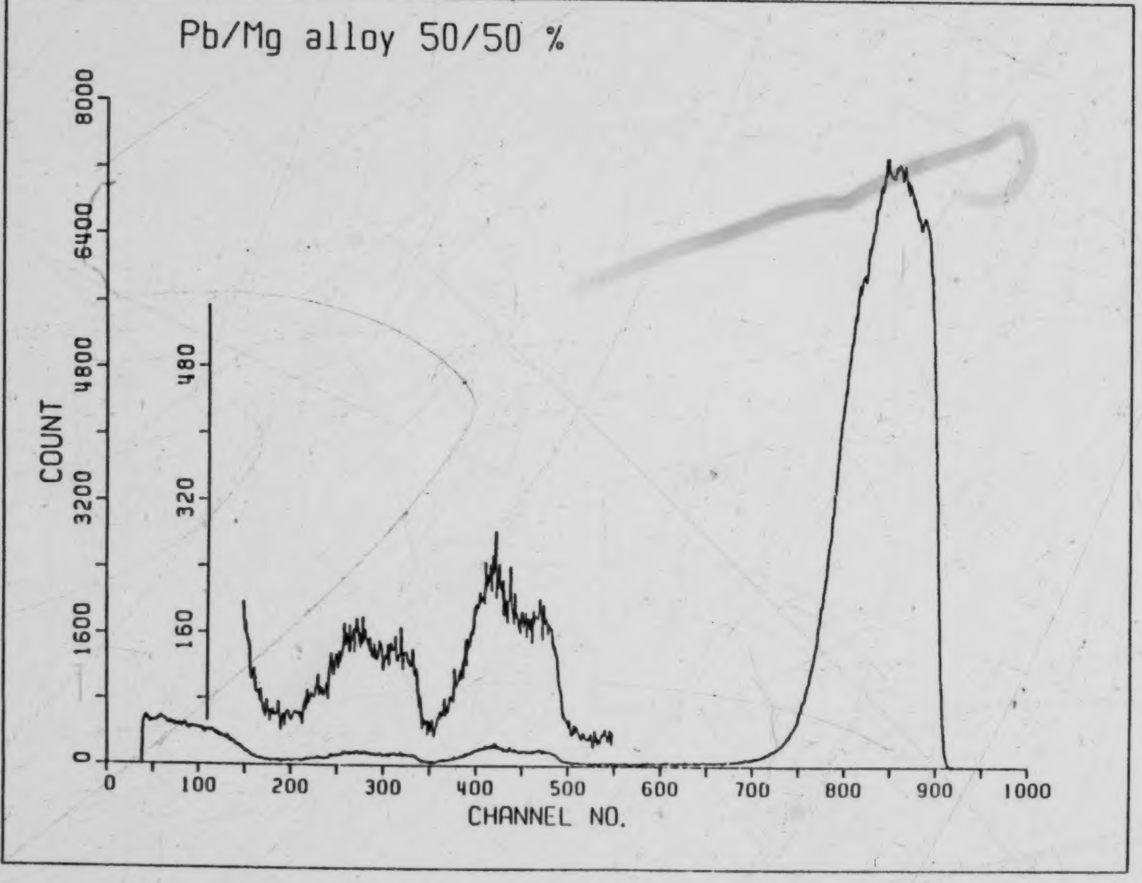


Figure 7-10. 2.0 MeV $_4He^+$ RBS spectrum from Pb/Mg alloy film deposited with 50/50(Pb/Mg) ion beam deposition dosage ratio.-2

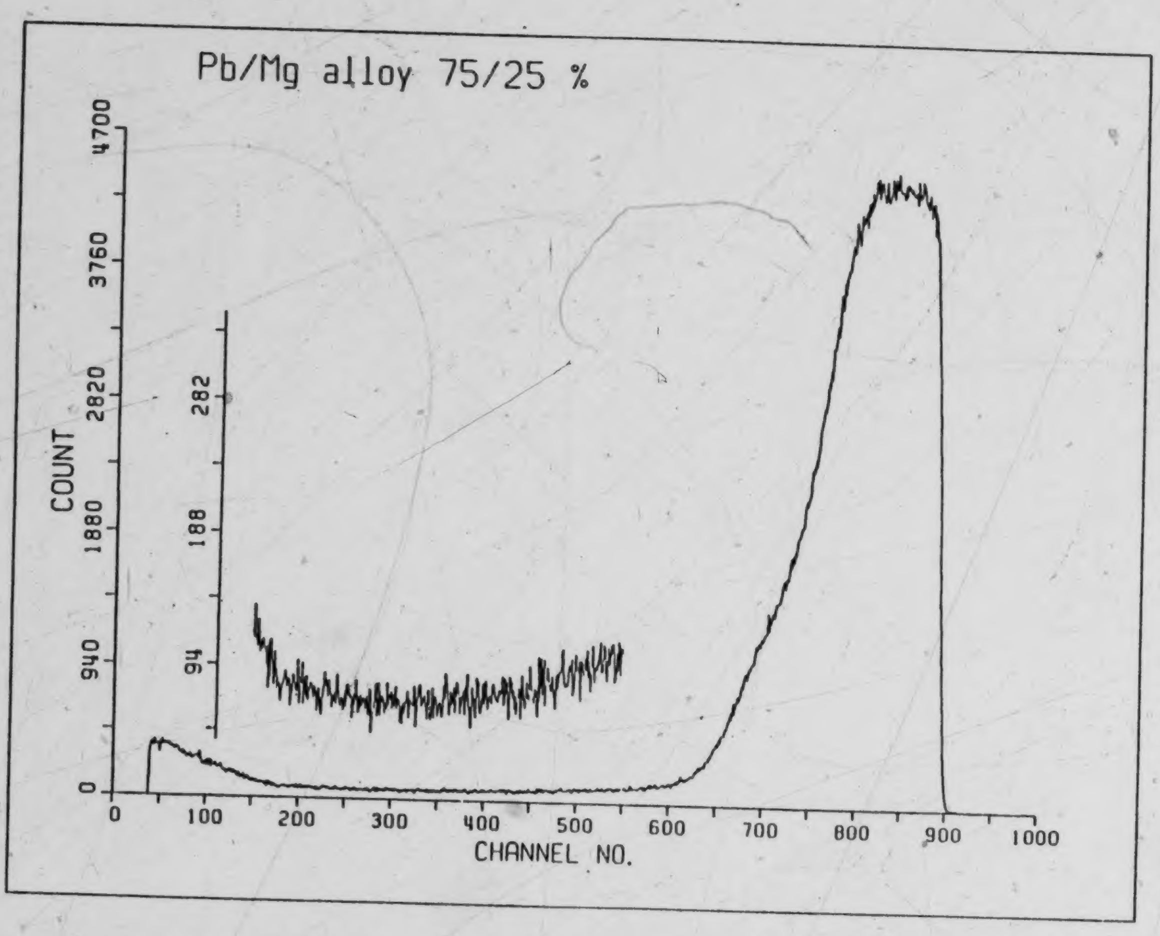


Figure 7-11. 2.0 MeV $^{4}\text{He}^{+}$ RBS spectrum from Pb/Mg alloy film deposited with 75/25(Pb/Mg) ion beam deposition dosage ratio.

## G. Analysis by SEM and TEM

The surface and cross-section of $Pb^+/Mg^+$ (50/50%) ion beam deposited films were examined by using a Phillips model SEM505, scanning electron microscope. The SEM is a most versatile instrument for the investigation of the microstructure of solid surfaces. In the SEM the reflected electrons or the secondary emitted electrons provide information of the surface topography of the specimen. Specimen preparation for a SEM is relatively simple. Pb and Mg were deposited on a vitreous carbon substrate and later this substrate was mounted on the SEM specimen stub using conductive adhesive.

Transmission Electron Microscopy (TEM) is one of the well established methods for the analysis of thin film structures. The transmission electron diffraction pattern of a thin film gives information about the crystal structure and crystalline orientation. A highly magnified image of the thin film provides information about the microstructure of the thin film. In general, the preparation of a specimen for TEM analysis requires special attention in reducing the specimen thickness to below 1000 Å to obtain a condition of transparency for electrons.

For the work discussed here, the Pb/Mg alloy film must be grown on an electrically conducting substrate, otherwise charge build-up on an insulator would quickly reduce the depositing ion beam current to zero. Using the generally accepted substrate of NaCl for TEM work, a thin conducting layer of carbon was deposited via a carbon arc discharge in vacuum. The NaCl/carbon then acted as the substrate for ion beam depositing the Pb/Mg films which were under investigation here. The films were removed from the substrate using distilled water and then mounted on a supporting copper grid to be inserted into the microscope.

The microscope used in these experiments was a Phillips model EM410, transmission electron microscope with 100 kV acceleration voltage which corresponds to the wavelength of 0.03702 Å. The diffraction pattern of crystalline material is regularly spaced spots for a single crystal and concentric rings for polycrystalline specimen. The diffraction maxima occurs when the electron waves are 'reflected' from planes of atoms in a crystal and satisfies the Bragg's law, interfering constructively on the diffraction plane. The radius of a ring or the distance to the diffraction spot from the center of the electron beam, R is given by(*14,15,16),

$$R=L\lambda/d \text{ ----------- } (7\text{-}15)$$

where

L : the camera length( the effective distance from the object to the diffraction pattern)

$\lambda$ : electron wave length

d : lattice plane distance

Plate 3 shows the electron diffraction pattern from 50 eV $Pb^+$ ion beam deposited film. The basic structure of Pb is f.c.c. and in the cubic system the relationship between interplanar spacing d and Miller indices(h,k,l) of the parallel palnes is given by(*14,15,16),

$$1/d^2=(h^2+k^2+l^2)/a^2=N/a^2 \text{ ------------ } (7\text{-}16)$$

where

a : lattice parameter

$N=h^2+k^2+l^2$, in case of f.c.c. N=3,4,8,11,12,16,19,20

The diameters of each ring have been measured from the enlarged photograph. From equation 7-15 and 7-16, N is given by,

$$N=(aR/L\lambda)^2 \text{ ------------- } (7\text{-}17)$$

L=275 mm, $\lambda$=0.03702 Å,a=4.9506 Å

The interplanar distances d have been calculated and checked against ASTM powder diffraction data(*17). Table 7-3 shows the comparison made with measured ring diameters and ASTM data of Pb. The interplanar spacings determined from the diffraction pattern of 50 eV $Pb^+$ ion beam deposited film show that they match well with reported ASTM data. But the intensity of the ring shows ion beam deposited film has a preferred orientation of (220) which is different from the powder diffraction data.

Plate 4 shows TEM diffraction pattern of 50 eV $Mg^+$ ion beam deposited film. With a similar method used in Pb film analysis, the interplanar distances were calculated and

Table 7-3
Pb thin film TEM diffraction pattern comparison with ASTM data

| ASTM data | | | | Measured data | |
|---|---|---|---|---|---|
| d(Å) | $I/I_0$ | hkl | equivalent dia.(mm) | measured dia.(mm) | intensity |
| 2.855 | 100 | 111 | 28.5 | 28.5 | |
| 2.475 | 50 | 200 | 33.0 | 33.5 | |
| 1.75 | 31 | 220 | 46.6 | 47 | highest |
| 1.493 | 32 | 311 | 32.0 | 54.6 | second |
| 1.429 | 9 | 222 | 57.0 | | |
| 1.238 | 2 | 400 | 65.8 | | |
| 1.1359 | 10 | 331 | 71.6 | 73 | |
| 1.1069 | 7 | 420 | 73.6 | 75 | |
| 1.0105 | 6 | 422 | 80.6 | 82 | |

compared with compiled ASTM powder diffraction data. As it was suggested from the RBS spectra, the diffraction pattern matches that of MgO rather than Mg. Table 7-4 shows the comparison between measured values from Mg film and ASTM data of MgO. A few missing rings in the measured data are considered to be due to the low intensity of the rings. The orientation of the MgO film produced by ion beam deposition of Mg is identical with that of ASTM data.

Table 7-4
MgO TEM diffraction pattern compared with ASTM data

| ASTM data | | | | Measured data | |
|---|---|---|---|---|---|
| d(Å) | $I/I_0$ | hkl | equivalent dia.(mm) | measured dia.(mm) | intensity |
| 2.431 | 10 | 111 | 33.5 | 33.5 | third |
| 2.106 | 100 | 200 | 38.7 | 39.0 | strongest |
| 1.489 | 52 | 220 | 54.7 | 55.0 | second |
| 1.270 | 4 | 311 | 64.1 | | |
| 1.216 | 12 | 222 | 67.0 | 67.5 | |
| 1.0533 | 5 | 400 | 77.3 | 78.0 | |
| 0.9665 | 2 | 331 | 84.3 | | |
| 0.9419 | 17 | 420 | 86.5 | 87.5 | |
| 0.8600 | 15 | 422 | 94.7 | 96.0 | |
| 0.8109 | 3 | 511 | 100.4 | | |

Plate 5 shows the electron diffraction pattern from a Pb/Mg 50/50 % composition alloy film. The measured interplanar spacings are 3.88, 2.86, 2.33, 2.14, 2.04, 1.63, 1.34, 1.15, 0.87 Å. There is no compiled data to be compared with this measurement and it is difficult to determine the basic structure of this unique composition using only the diffraction pattern. This diffraction pattern does not appear to approximate that of a superimposition of Pb and

MgO. Because of the nature of the film growth technique : that of sequentially layering and mixing thin deposits of Pb and Mg, there was a concern that separate layers of the two different elements could exist in the total film. The diffraction pattern suggests that the two elements which were initially deposited in separate layers became mixed to form a new structure.

Plate 1 shows the surface topography of Pb/Mg(50/50%) ion beam deposited thin film. Plate 2 shows a cross section of a rather thick(about 8μ) Pb/Mg(50/50%) deposited alloy film. The surface topography shows a collection of small grains of 0.2-0.5μ. The rather grainy feature is considered to be due to the extremely low flux rate(about 0.3 Å/sec). Both specimens are grown by $Pb^+/Mg^+$ ion beam deposition with a deposition switching batch dosage of 1000μC/1000μC. The crack seen between the thick top layer and the next layer is caused by the mechanical stress applied while breaking the specimen to exposure the cross section. There are no visible signs of the separate layers which were applied during the film growth.

The film growth structure is unique compared with cross sections of films grown by conventional techniques. With the substrate at room temperature, films grown by conventional techniques normally show columnar defects(*18). The columnar defects are caused by lack of lateral diffusion of arrival particles. Due to the high particle energy of 50 eV compared with conventional techniques which produce particles with energy less than 10 eV, the columnar growth defects did not form with ion beam deposited films.

Plate 1.

SEM surface topography of Pb/Mg(50/50 %) alloy film deposited by 50 eV sequential ion beam of $Pb^+/Mg^+$ with sequential deposition batch dosage of 1000μC/1000μC.

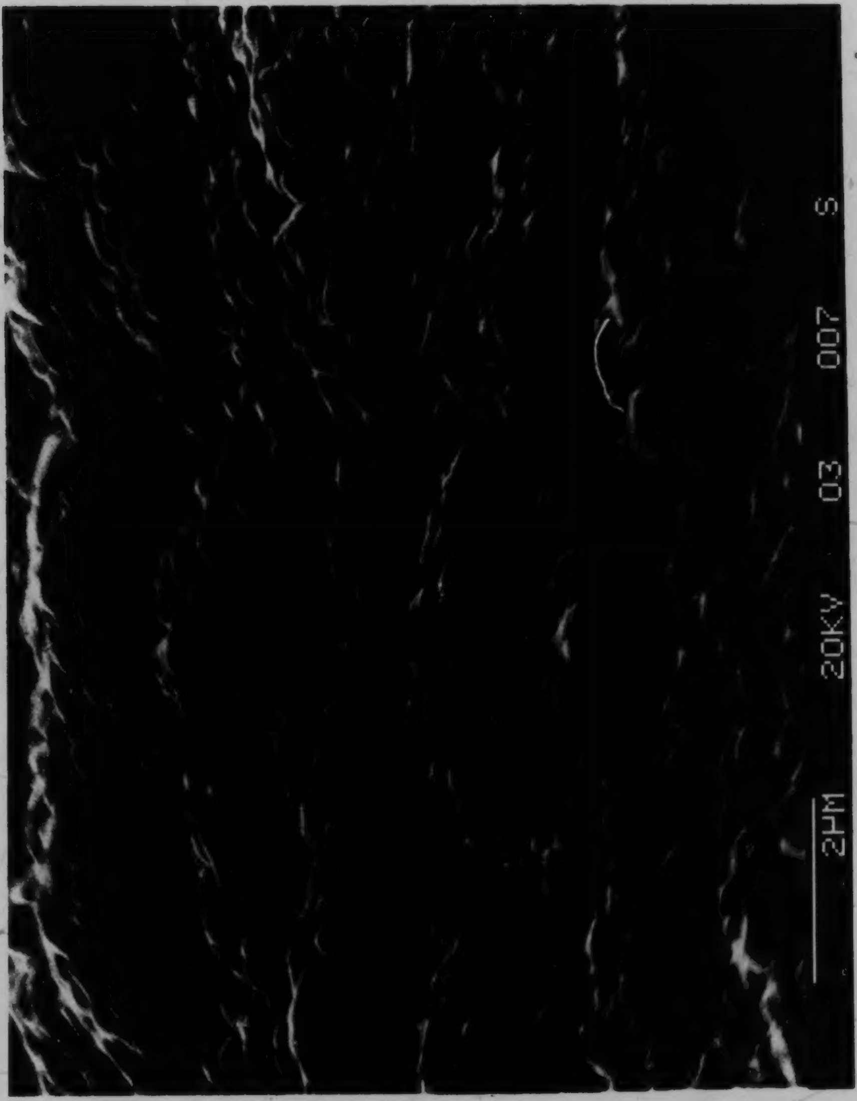
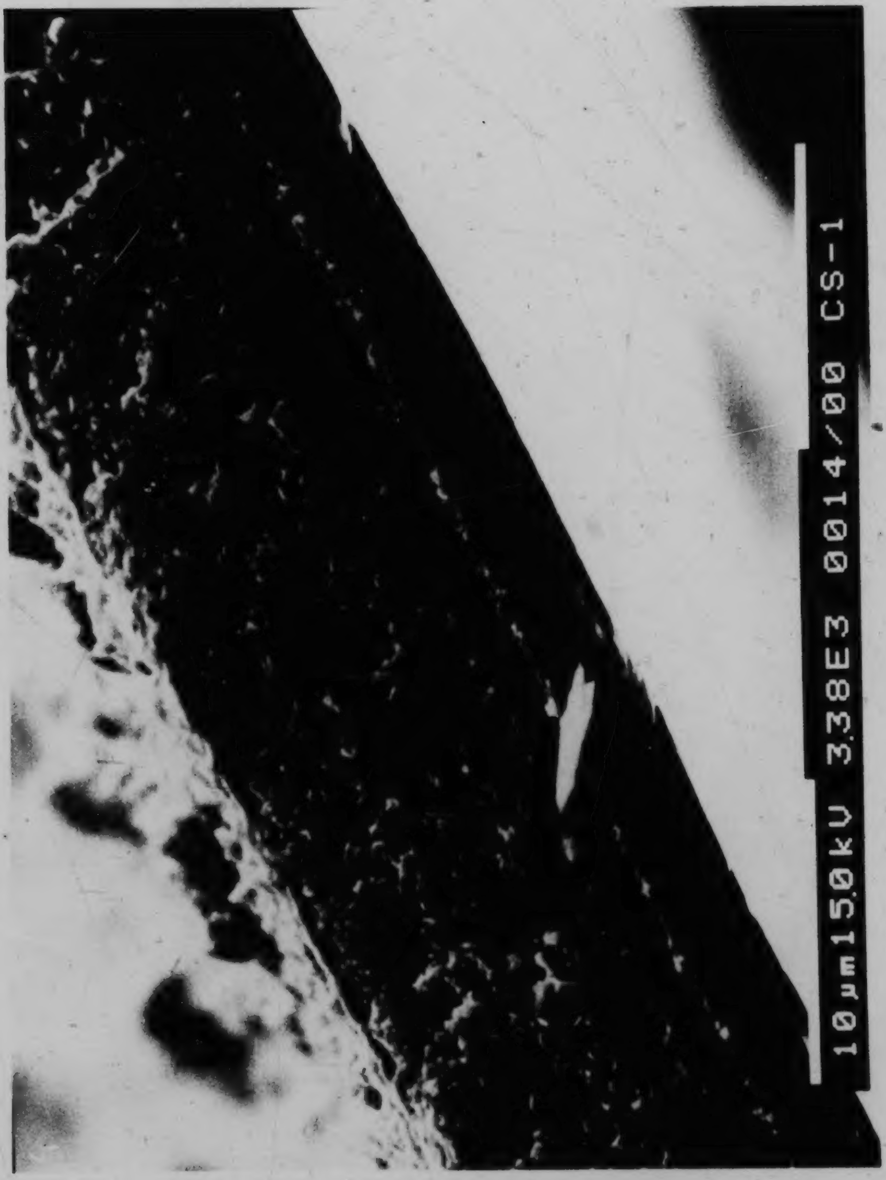

2µm
20KV
03
007
S

Plate 2.

SEM cross section topography of Pb/Mg(50/50 %) alloy film deposited by 50 eV sequential ion beam of $Pb^+/Mg^+$ with sequential deposition batch dosage of 1000μC/1000μC.


10µm 15.0kV 3.38E3 0014/00 CS-1

155

Plate 3.

TEM diffraction pattern of 50 eV $Pb^+$ beam deposited film.

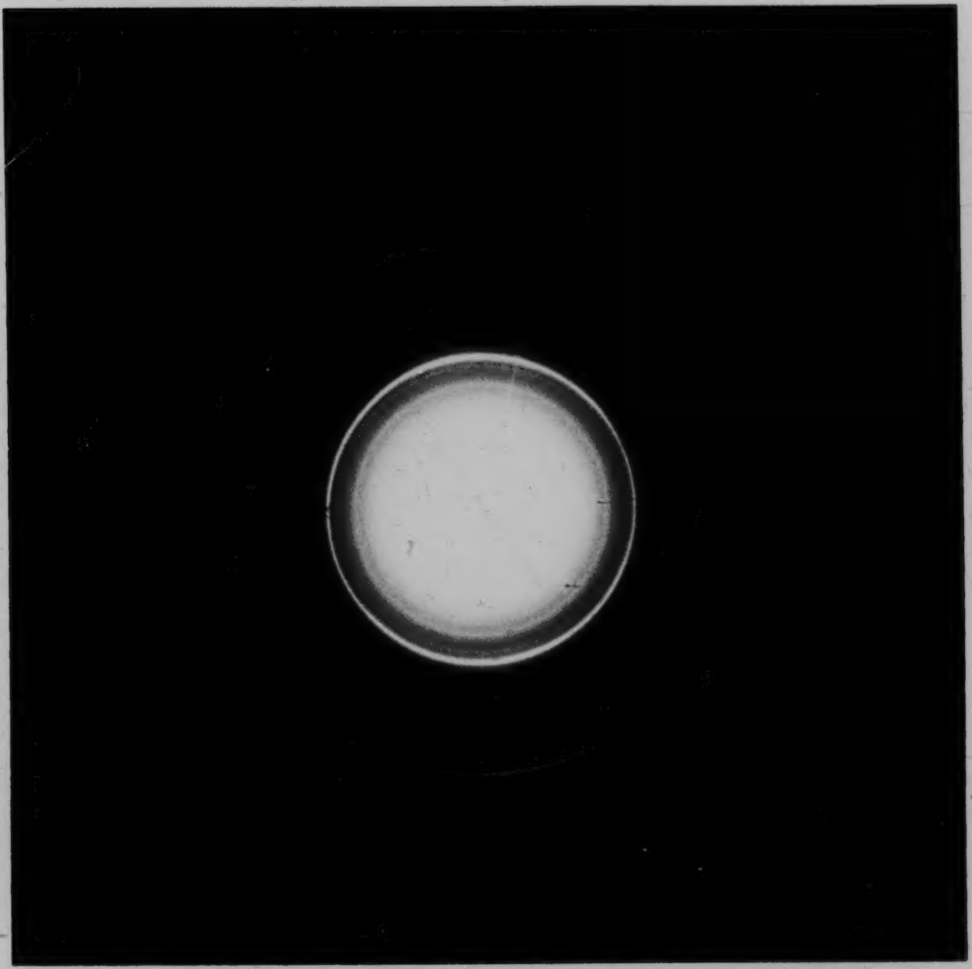


Plate 4.

TEM diffraction pattern of 50 eV $Mg^+$ beam deposited film.

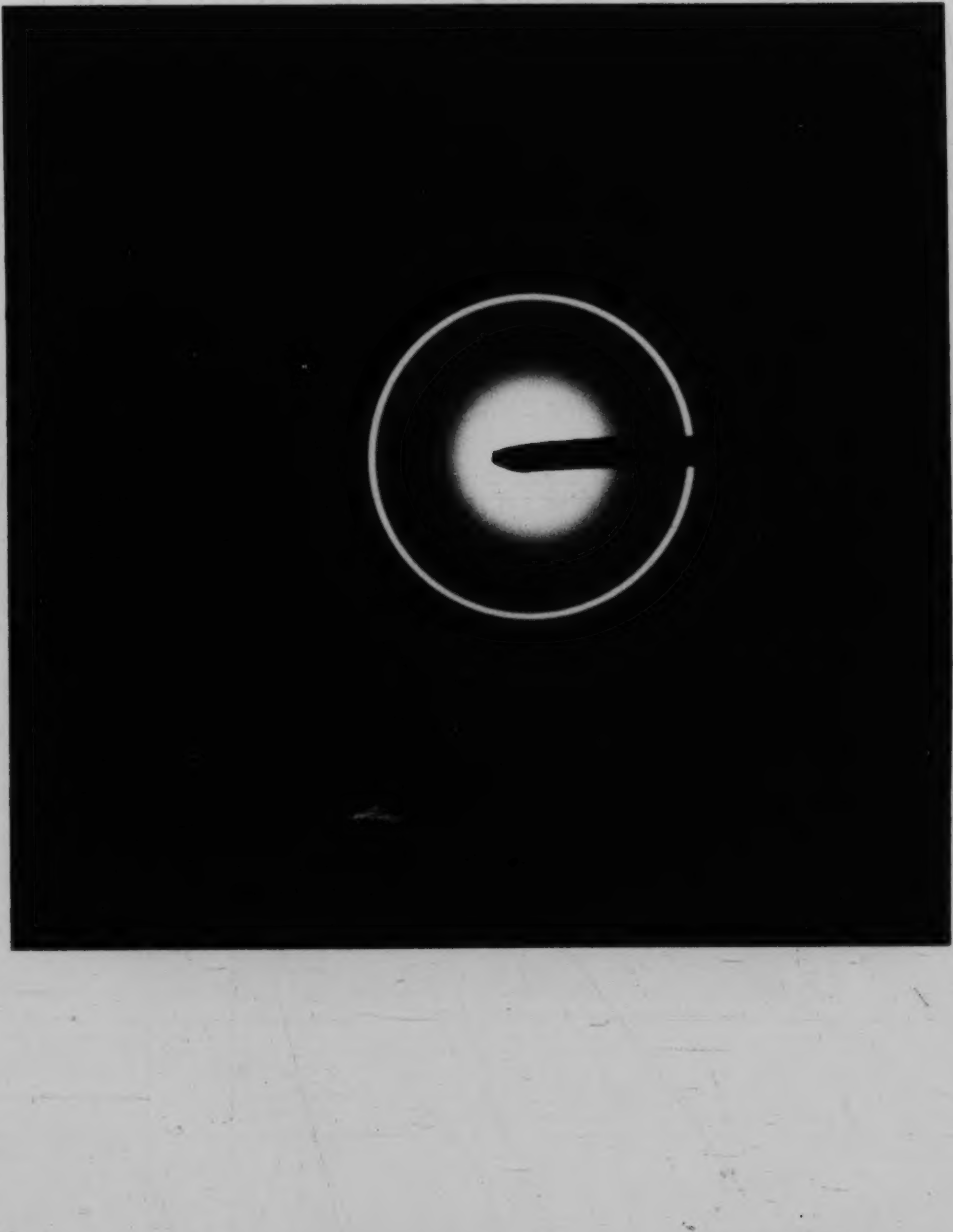
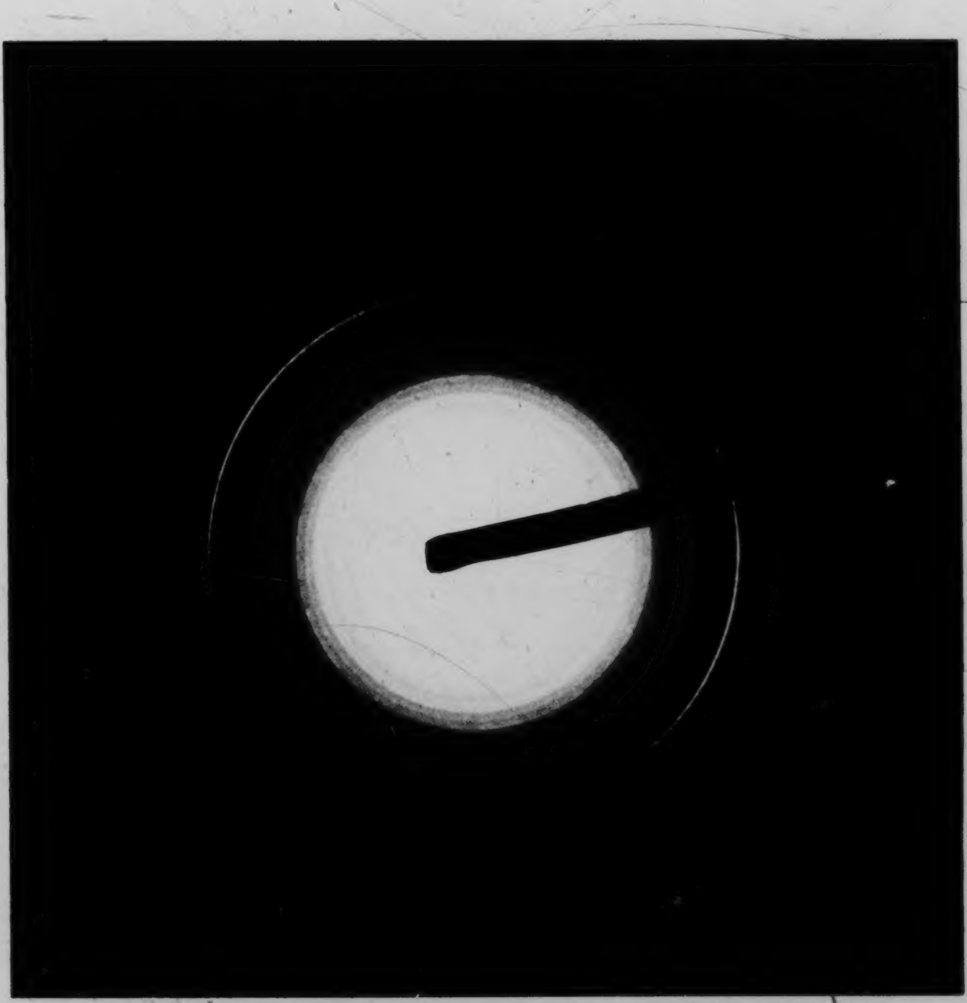


Plate 5.

TEM diffraction pattern Pb/Mg(50/50 %) alloy film deposited by 50 eV sequential ion beam deposition of $Pb^+/Mg^+$ with sequential deposition batch dosage of 1000μC/1000μC.



## VIII. Limitations of the Present System

The major limitations of this system are : (a) the low film growth rate, (b) the range of film material. The low ion beam current of about 10 μA is too low to allow high film growth processes. An ion source which can deliver ion currents in the milliamperes range is recommended to achieve reasonable film growth rates and to produce larger specimens which can be subjected to electrical and mechanical test.

The present ion source can not produce furnace temperatures high enough to evaporate and ionize refractory metals. An ion source which can produce ions of low vapor pressure elements in the range of $1 \times 10^{-3}$ Torr at 2500 °K, is recommended for an alloying experiment using refractory metal elements.

The thermal isolation of the dual furnace has to be increased to accommodate a combination of low and high melting temperature materials. With the present configuration, the temperature isolation between the two furnaces is approximately 500 °K.

Due to the nonuniform current density distribution over the focused ion beam, a simple spot deposition cannot produce a uniform thickness over all of the deposited area. The focusing characteristics of the ion beam varies as ion species is changed because of the different charge to mass ratio. When alloying with two different ion beams in the same ion beam system, the two beams have different current density distribution and the resulting alloy composition distribution becomes non-uniform. Using only a small portion of the beam is one way to reduce lateral density variations but growth rate will be dropped proportionally to the used portion of beam. A more efficient method could be to scan the beam over a stationary substrate horizontally and vertically, or, alternatively, moving the substrate while maintaining the beam trajectory unchanged. An electrostatic ion beam scanner located between the decelerator and the target is recommended to achieve homogeneous film composition.

In order to deposit insulating films, the system requires a neutralizing sea of electrons supplied from a hot filament near the target to prevent positive charge build up on the target.

The lack of in situ analytical equipment with this system makes the investigation of uncontaminated specimens during growth process impossible.

# IX. Conclusions

This chapter summarizes the present study of the computer controlled sequential ion beam deposition system and binary alloy metallic films produced by the system.

## A. Sequential ion beam deposition system

A computer controlled system has been designed to make a thin film deposition facility capable of delivering two different ion beams sequentially to a substrate. Some important features have been incorporated into the design, namely: programmable control over the beam energy, deposition dosage, beam focusing, mass selection and beam shaping. The operation of the ion source also has been discussed in detail. A brief summary of the features of the deposition system follows here;

a) Computer control hardware

- Master computer : IBM PC
- Slave computer : Motorola MC6809 8 bit microprocessor based system designed to handle 72 data acquisition and control channels.
- Data acquisition and control channels :

  32 A/D channels : 8 bit A/D, data from various power supplies, voltage, current and vacuum level measurement.

  24 D/A channels : 8 bit D/A, power supply voltage

and/or current control.

16 AC load control channels : up to 15 Ampere, 115 V,60 HZ, activates/deactivates and monitors vacuum pump motors, vacuum pump heaters, solenoids, heat exchanger and DC power supplies.

High voltage isolation : each channel except AC load controllers are rated at 7.5 kV between input and output.

b) System software

- System start-up and shut down routine.
- Ion source outgassing routine with programmable outgassing speed.
- Master operation routine
    - Ion source control routine (constant discharge current and voltage mode)
    - Visual screen mode D/A reference setting.
    - Data logging
    - Beam switching routine.
- Slave computer operation routine
    - Read in A/D units and AC load control units
    - Control D/A units and AC load control units.
    - Listen to master and execute command. Report to master whenever requested by master.

c Ion beam system

- Simultaneous production of two different ion species from an ion source with dual furnaces.
- Ion species : gas, solid ion beam

- Ion energy : 0 eV to 4 keV
- Ion current : up to a few tens of μA
- Ion source operation time : up to 100 hours
- Mass selectivity : $M/\Delta M \approx 4$
- Mass selection : 1-600 AMU
- Vacuum conditions : $1 \times 10^{-7}$ Torr in ion beam transport chamber, $1 \times 10^{-8}$ Torr in target chamber

**B. Pb/Mg binary alloy thin film deposition**

The main focus of this research work at this stage was to build a binary alloy deposition system using a single ion source and to investigate the produced alloy films to confirm the design object of the system. The deposition of binary alloy using $Pb^+$ and $Mg^+$ sequential ion beams has been carried out successfully. The results of the film composition analysis by RBS show that the system is capable of delivering two sequential ion beams to produce binary alloys with in-situ control over the alloy composition.

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# XI. APPENDIX I

## SLAVE COMPUTER OPERATING ROUTINE

```
                     NAM     SLAVE1
                     OPT     NOG
               *****************************************
               *
               *   SLAVE COMPUTER OPERATING SYSTEM
               *          A SYSTEM DEDICATED FOR A/D,D/A AND ON/OFF
               *          CONTROL OF LOW ENERGY ION BEAM DEPOSITION
               *          SYSTEM
               *          THIS SYSTEM IS INTERFACED WITH IBM PC AS MASTER
               *          AND THE MASTER HAS TO PROVIDE NECESSARY OPERATING
               *          PARAMETERS.
               *
               *        PROGRAMMED BY J. AHN
               *        DEPT. OF ELEC. ENG
               *        UNIV. OF ALBERTA
               *
               *        DECEMBER, 1984
               *
               *
               *****************************************
               *
               *    GLOBAL MODULE EQUATES
               *
F800           ROM1    EQU    $F800              #1 EPROM $F800-$FFFF
0000           RAM1    EQU    $0000              #1 RAM $0000-$07FF
0800           ROMSIZ  EQU    $800               ROM/RAM SIZE 2K BYTES
F000           ROM2    EQU    ROM1-ROMSIZ        #2 EPROM $F000-$F7FFF
4006           ACIAAD  EQU    $4006              A/D CONTROL  ACIA
5006           ACIADA  EQU    $5006              D/A CONTROL  ACIA
6006           ACIASW  EQU    $6006              ON/OFF SWITCH CONTROL  ACIA
7006           ACIAPC  EQU    $7006              IBM PC INTERFACE  ACIA
7007           PCRTX   EQU    ACIAPC+1           IBM PC ACIA RX/TX REG.
7006           PCSTS   EQU    ACIAPC             IBM PC ACIA STATUS/CONTROL REG.
4007           ADRTX   EQU    ACIAAD+1           A/D ACIA RX/TX REG.
4006           ADSTS   EQU    ACIAAD             A/D ACIA STATUS/CONTROL REG.
5007           DARTX   EQU    ACIADA+1           D/A ACIA  RX/TX REG.
5006           DASTS   EQU    ACIADA             D/A ACIA STATUS/CONTROL REG.
6007           SWRTX   EQU    ACIASW+1           ON/OFF ACIA RX/TX REG.
6006           SWSTS   EQU    ACIASW             ON/OFF ACIA STATUS/CONTROL REG.
0040           SWON    EQU    $40                SWITCH ON CONTROL(BIT6=1,BIT5=0)
0000           SWOFF   EQU    $00                SWITCH OFF CONTROL
0020           SWREAD  EQU    $20                READ SWITCH CONTROL SET
```

```
00046 00044          3800     PTM1     EQU    $3800              TIMER1,PC COMM BAUD,A/D,D/A TIME OUT
00047 00045          2800     PTM2     EQU    $2800              TIMER2, BEAM SWITCHING CONTROL
00048 00046          8008     PIA      EQU    $8008              PIA STARTING ADDRESS
00049 00047          E800     ROM3     EQU    ROM2-ROMSIZ        #3 EPROM   $E800-$EFFF
00050 00048          E000     ROM4     EQU    ROM3-ROMSIZ        #4 EPROM   $E000-$E7FF
00051 00049          D800     ROM5     EQU    ROM4-ROMSIZ        #5 EPROM   $D800-$DFFF
00052 00050          D000     ROM6     EQU    ROM5-ROMSIZ        #6 EPROM   $D000-$D7FF
00053 00051          0800     RAM2     EQU    RAM1+ROMSIZ        #2 RAM  $0800-$0FFF
00054 00052          1000     RAM3     EQU    RAM2+ROMSIZ        #3 RAM  $1000-$17FF
00055 00053          1800     RAM4     EQU    RAM3+ROMSIZ        #4 RAM  $1800-$1FFF
00056 00054          2000     RAM5     EQU    RAM4+ROMSIZ        #5 RAM  $2000-$27FF
00057 00055          2800     RAM6     EQU    RAM5+ROMSIZ        #6 RAM  $2800-$2FFF
00058 00056          3801     PTMST1   EQU    PTM1+1             TIMER1 STATUS
00059 00057          3800     PTMC11   EQU    PTM1               TIMER1, #1,3 CONTROL REG.
00060 00058          3801     PTMC12   EQU    PTM1+1             TIMER1, #2 CONTROL REG.
00061 00059          3802     PTMM11   EQU    PTM1+2             TIMER1 LATCH #1
00062 00060          3804     PTMM12   EQU    PTM1+4             TIMER1 LATCH #2
00063 00061          3806     PTMM13   EQU    PTM1+6             TIMER1 LATCH #3
00064 00062          2801     PTMST2   EQU    PTM2+1             TIMER2 STATUS
00065 00063          2800     PTMC24   EQU    PTM2               TIMER2 CONTROL #1,3
00066 00064          2801     PTMC22   EQU    PTM2+1             TIMER2 CONTROL #2
00067 00065          2802     PTMM21   EQU    PTM2+2             TIMER2 LATCH #1
00068 00066          2804     PTMM22   EQU    PTM2+4             TIMER2 LATCH #2
00069 00067          2806     PTMM23   EQU    PTM2+6             TIMER2 LATCH #3
00070 00068          8008     PIAPA    EQU    PIA                PIA PORT A
00071 00069          800A     PIAPB    EQU    PIA+2              PIA PORT B
00072 00070          8009     PIACA    EQU    PIA+1              PIA CONTROL REG. A
00073 00071          800B     PIACB    EQU    PIA+3              PIA CONTROL REG. B
00074 00072          8008     PIADRA   EQU    PIA                PIA DATA DIRECTION REG. A
00075 00073          800A     PIADRB   EQU    PIA+2              PIA DATA  DIRECTION REG. B
00076 00074          001A     NOINTR   EQU    $1A                RXTX FORMAT(8BIT,1STOP,E,/64CLK NO RXTX INTR.)
00077 00075          00BA     RTXINT   EQU    $BA                RXTX INTR. ON
00078 00076          009A     RXINTR   EQU    $9A                RXTX FORMAT(8BIT,1STOP,/64,RX INTR. ON)
00079 00077          003A     TXINTR   EQU    $3A                RXTX FORMAT(8BIT,1STOP,E,/64,TX INTR.ON)
00080 00078          0016     ADRXOF   EQU    $16                A/D DEVICE RX FORMAT(8BIT,1STOP,/64,NO INTR.)
00081 00079          0096     ADRXON   EQU    $96                A/D DEVICE RX INTRPT. ON
00082 00080          00B6     ADRTON   EQU    $B6
00083 00081          0095     PCRXON   EQU    $95                PC RX INTR. ON(8BIT,1STOP,N,/16,INTR.RX ON,TX OFF
00084 00082          00B5     PCRTON   EQU    $B5                PC RX,TX INTR. ON
00085 00083          0003     MRST     EQU    3                  ACIA MASTER RESET CONTROL WORD
00086 00084          03E8     TO1      EQU    1000               1 MS TIME OUT
00087 00085          0BB8     TO3      EQU    3000               3 MS TIME OUT
```

```
0FA0    T04     EQU   4000       4 MS TIME OUT
2710    T010    EQU   10000      10 MS TIME OUT
1770    T06     EQU   6000       6 MS TIME OUT
32C8    T013    EQU   13000      13 MS TIME OUT
3E80    T016    EQU   16000      16 MS TIME OUT
00F0    MTABLE  EQU   $F0        COMMAND,MASTER REFERENCE TABLE
00F1    HENGTM  EQU   $F1        COMMAND,HIGH ENERGY TIMING
00F2    LENGTM  EQU   $F2        COMMAND,LOW ENERGY TIMING
00F3    OFFTM   EQU   $F3        COMMAND,BEAM OFF TIMING
00F7    TXCTL   EQU   $F7        PC TX CONTROL COMMAND,RX
00F9    DACONT  EQU   $F9        D/A CONTROL VALUE COMMAND
00F0    FIRST   EQU   $F0        COMM. FIRST BYTE IN DATA PACKET
00F1    SECOND  EQU   $F1        COMM. SECOND BYTE IN DATA PACKET
00F2    LAST    EQU   $F2        COMM. LAST BYTE IN DATA PACKET
00F5    DABAD   EQU   $F5        COMM.,D/A ERROR
00F6    PCBAD   EQU   $F6        COMM.,TX,PC COMMINICATION ERROR
00A1    TMRST   EQU   $A1        TIMER MASTER RESET
000B    CS      EQU   11         A/D CHIP SELECT CONTROL COUNTER
00E3    TMON2   EQU   $E3        TIMER#2,INTERNAL CLK,INTR. ON,ONESHOT
00A3    TMOFF2  EQU   $A3        TIMER #2, INTR. OFF
0062    TMON1   EQU   $62        TIMER #1, INTR. ON
0022    TMOFF1  EQU   $22        TIMER #1, INTR. OFF
00E0    CSON    EQU   $E0        CS TIMER,EXT. CLK,ONESHOT,INTR.ON,TO
0020    CSOFF   EQU   $20        CS TIMER, INTR OFF
0001    SFIL    EQU   1          ION SOURCE FILAMENT
0002    FFIL    EQU   2          FURNACE FILAMENT
0003    HIVOLT  EQU   3          HIGH VOLTAGE
0004    ANODE   EQU   4          ANODE VOLTAGE
0005    FOCUS   EQU   5          FOCUS VOLTAGE
0006    VBEAM   EQU   6          ION BEAM ENERGY
0007    IBEAM   EQU   7          ION BEAM CURRENT
0008    HDEF    EQU   8          HORIZONTAL DEFLECTION VOLTAGE
0009    VDEF    EQU   9          VERTICAL DEFLECTION VOLTAGE
000A    MAGNET  EQU   10         MAGNET CURRENT
000B    VELV    EQU   11         VELOCITY FILTER POTENTIAL
000C    VELR1   EQU   12         VEL. FILTER RIGHT SHIM 1 POTENTIAL
000D    VELR2   EQU   13         VEL. FILTER RIGHT SHIM 2 POTENTIAL
000E    VELR3   EQU   14         VEL. FILTER RIGHT SHIM 3 POTENTIAL
000F    VELL1   EQU   15         VEL. FILTER LEFT SHIM 1 POTENTIAL
0010    VELL2   EQU   16         VEL. FILTER LEFT SHIM 2 POTENTIAL
0011    VELL3   EQU   17         VEL. FILTER LEFT SHIM 3 POTENTIAL
0012    VELBAL  EQU   18         VEL. FILTER BALANCE POTENTIAL
```

```
00130 00128           0013    VELM    EQU    19            VEL. FILTER MIDDLE SHIM POTENTIAL
00131 00129           0014    SCHMBP  EQU    20            SOURCE CHAMBER PRESSURE
00132 00130           0015    TCHMBP  EQU    21            TARGET CHAMBER PRESSURE
00133 00131           0016    SFLP    EQU    22            SOURCE FORELINE PRESSURE
00134 00132           0017    TFLP    EQU    23            TARGET FORELINE PRESSURE
00135 00133           0018    GASP    EQU    24            SOURCE GAS PRESSURE
00136 00134           0001    RPS     EQU    1             SOURCE CHAMBER ROTARY PUMP
00137 00135           0002    RPT     EQU    2             TARGET CHAMBER ROTARY PUMP
00138 00136           0003    DPS     EQU    3             SOURCE CHAMBER DIFFUSION PUMP
00139 00137           0004    DPT     EQU    4             TARGET CHAMBER DIFFUSION PUMP
00140 00138           0005    TURBO   EQU    5             TURBO PUMP
00141 00139           0006    GATE    EQU    6             GATE VALVE IN TARGET CHAMBER
00142 00140           0007    GHPRP   EQU    7             GAS HANDLING PLANT ROTARY PUMP
00143 00141           0008    HTRTRB  EQU    8             TURBO PUMP HEATER
00144 00142           0009    MAGSW   EQU    9             MAGNET POWER SUPPLY
00145 00143           000A    DECEL   EQU    10            DECELLERATOR
00146 00144           000B    SFILSW  EQU    11            SOURCE FIL: POWER SUPPLY
00147 00145           000C    FFILSW  EQU    12            FURNACE FIL. POWER SUPPLY
00148 00146           000D    SPRSW   EQU    13            SOURCE CHAMBER PRESSURE GAUGE CONTROLLER
00149 00147           000E    TPRSW   EQU    14            TARGET CHAMBER PRESSURE GAUGE CONTROLLER
00150 00148           000F    HIVSW   EQU    15            HIGH VOLTAGE POWER SUPPLY UNIT
00151 00149           0000    WORKPG  EQU    RAM1          WORKING PAGE, 0000
00152 00150           0000            SETDP  WORKPG        SET DIRECT PAGE AT 0000
00153 00151 0100                    ORG    WORKPG+256    WORKING AREA 512 BYTES
00154 00152 00FF                    ORG    *-1
00155 00153           00FF    MEMFLG  EQU    *
00156 00154 00FD                    ORG    *-2
00157 00155           00FD    VECTAB  EQU    *
00158 00156 00FB                    ORG    *-2
00159 00157           00FB    BASEPG  EQU    *
00160 00158 00F1                    ORG    *-10
00161 00159           00F1    STACK   EQU    *
00162 00160 0080                    ORG    WORKPG+128
00163 00161           0080    USTACK  EQU    *
00164 00162 0081                    ORG    *+1
00165 00163           0081    RXBUF   EQU    *             PC RX BUFFER,128 BYTES LONG
00166 00164 0101                    ORG    *+128
00167 00165           0101    RXBEND  EQU    *
00168 00166 0103                    ORG    *+2
00169 00167           0103    TXBUF   EQU    *             PC TX BUFFER, 256 BYTES LONG
00170 00168 0203                    ORG    *+256
00171 00169           0203    TXBEND  EQU    *
```

```
00172 00170 0205                    ORG    *+2
00173 00171            0205  RXSTRT EQU    *          PC RX BEGINNING OF DATA IN BUFFER,NEXT DECODE LOC
00174 00172 0207                    ORG    *+2
00175 00173            0207  TXSTRT EQU    *          PC TX BEGINNING OF DATA IN BUFFER,LOCATION TO BE
00176 00174 0209                    ORG    *+2
00177 00175            0209  RXEND  EQU    *          PC RX END OF DATA IN BUFFER,RECEIVED DATA WILL BE
00178 00176 020B                    ORG    *+2
00179 00177            020B  TXEND  EQU    *          TX DATA END,TRANSMISSION WILL STOP WHEN THIS DATA
00180 00178 020D                    ORG    *+2
00181 00179            020D  TXOFF  EQU    *          TX OFF REQUEST FLAG
00182 00180 020F                    ORG    *+2
00183 00181            020F  PCEROR EQU    *          PC RX,TX ERROR FLAG
00184 00182 0210                    ORG    *+1
00185 00183            0210  ADUAL  EQU    *          SINGLE ELEMENT : 0,  DUAL : 1
00186 00184 0211                    ORG    *+1
00187 00185            0211  DDUAL  EQU    *
00188 00186 0212                    ORG    *+1
00189 00187            0212  DUALST EQU    *          DUAL BEAM START FLAG
00190 00188 0213                    ORG    *+1
00191 00189            0213  HITM1  EQU    *          HIGH ENERGY  BEAM TIME IN SEC.
00192 00190 0215                    ORG    *+2
00193 00191            0215  HITM2  EQU    *
00194 00192 0217                    ORG    *+2
00195 00193            0217  LOTM1  EQU    *          LOW ENERGY BEAM TIME IN SEC.
00196 00194 0219                    ORG    *+2
00197 00195            0219  LOTM2  EQU    *
00198 00196 021B                    ORG    *+2
00199 00197            021B  SWTM   EQU    *          BEAM SWITCHING DEAD TIME IN SEC.
00200 00198 021D                    ORG    *+2
00201 00199            021D  ADATA1 EQU    *          A/D DATA TABLE SET #1
00202 00200 023D                    ORG    *+32
00203 00201            023D  ADATA2 EQU    *          A/D DATA TABLE SET #2
00204 00202 025D                    ORG    *+32
00205 00203            025D  DAC1   EQU    *          D/A CONTROL TABLE SET #1
00206 00204 0275                    ORG    *+24
00207 00205            0275  DAC2   EQU    *          D/A CONTROL TABLE SET #2
00208 00206 028D                    ORG    *+24
00209 00207            028D  NFMTBL EQU    *
00210 00208 029D                    ORG    *+16       ON/OFF SWITCH MASTER TABLE
00211 00209            029D  DATEMP EQU    *          D/A MASTER REF. TEMPORARY STORAGE
00212 00210 02DD                    ORG    *+64
00213 00211            02DD  ADMODE EQU    *          CURRENT MODE STORAGE
```

```
00214 00212 02DE                    ORG    *+1
00215 00213            02DE  NFMODE EQU    *
00216 00214 02DF                    ORG    *+1
00217 00215            02DF  ADRMOD EQU    *
00218 00216 02E0                    ORG    *+1
00219 00217            02E0  ADTMOD EQU    *
00220 00218 02E1                    ORG    *+1
00221 00219            02E1  SWRMOD EQU    *
00222 00220 02E2                    ORG    *+1
00223 00221            02E2  SWTMOD EQU    *
00224 00222 02E3                    ORG    *+1
00225 00223            02E3  ADUP   EQU    *                     A/D CRRENT DATA
00226 00224 02E4                    ORG    *+1
00227 00225            02E4  DACH   EQU    *                     D/A CHANNEL NUMBER STORAGE
00228 00226 02E5                    ORG    *+1
00229 00227            02E5  DAERR  EQU    *                     D/A NEW CONTROL VALUE
00230 00228 02E6                    ORG    *+1
00231 00229            02E6  BMENG  EQU    *
00232 00230 02E7                    ORG    *+1                   BEAM ENERGY TEMPORARY STORAGE
00233 00231            02E7  BMCNT  EQU    *                     BEAM SWITCHING COUNTER
00234 00232 02E8                    ORG    *+1
00235 00233            02E8  ADCH   EQU    *                     A/D CHANNEL NUMBER STORAGE
00236 00234 02E9                    ORG    *+1
00237 00235            02E9  NFCH   EQU    *                     ON/OFF CHANNEL NUMBER STORAGE
00238 00236 02EA                    ORG    *+1
00239 00237            02EA  PCEFLG EQU    *
00240 00238 02EB                    ORG    *+1
00241 00239            02EB  NFLIST EQU    *                     ON/OFF ACTIVE CHANNEL LIST
00242 00240 02FB                    ORG    *+16                  16 CHANNELS MAXIMUM
00243 00241            02FB  TXNUM  EQU    *                     NUMBER OF BYTES IN TX BUFFER
00244 00242 02FD                    ORG    *+2
00245 00243            02FD  RXNUM  EQU    *                     NUMBER OF BYTES IN RX BUFFER
00246 00244 02FF                    ORG    *+2
00247 00245            02FF  ADNXT  EQU    *                     NEXT A/D CHANNEL NUMER STORAGE
00248 00246 0300                    ORG    *+1
00249 00247            0300  TEMPO  EQU    *
00250 00248 0301                    ORG    *+1
00251 00249            0301  SWCHG  EQU    *
00252 00250 0302                    ORG    *+1
00253 00251            0302  SWNEW  EQU    *
00254 00252 0303                    ORG    *+1
00255 00253            0303  IQCNT  EQU    *
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00256 00254 0304                    ORG     *+1
00257 00255           0304    IQMAP EQU     *
00258 00256 0305                    ORG     *+1
00259 00257           0305  DAINT1  EQU     *                 D/A INITIAL FLAG TABLE SET #1
00260 00258 031D                    ORG     *+24
00261 00259           031D  DAINT2  EQU     *                 D/A INITIAL FLAG SET #2
00262 00260 0335                    ORG     *+24              D/A INITIAL FLAG SET #2
00263 00261           0335  NFINT   EQU     *
00264 00262 0345                    ORG     *+16              ON/OFF INITIAL FLAG TABLE
00265 00263           0345  BEAMOD  EQU     *
00266 00264 0346                    ORG     *+1
00267 00265           0346  MOVFLG  EQU     *
00268 00266 0347                    ORG     *+1
00269 00267           0347  FMASK   EQU     *
00270 00268 0348                    ORG     *+1               FIRQ(WARM STARTUP) FLAG
00271 00269                 **********
00272 00270                 *  RESET ENTRY ROUTINE
00273 00271                 *
00274 00272                 **********
00275 00273 F000                    ORG     $F000
00276 00274 F000 32   8D 10ED KRESET LEAS   STACK,PCR         SET STACK LOCATION
00277 00275 F004 1A   50            ORCC    #$50              MASK F,I INTERRUPT
00278 00276                 **********************************
00279 00277                 *
00280 00278                 *    RAM TEST
00281 00279                 *         AFTER TESTING OF EACH BLOCK(2K BYTES), MEMORY FLAG BIT IS
00282 00280                 *         SET ONLY WHEN THE BLOCK PASSED THE TEST.
00283 00281                 *         BIT 0 : RAM #1,-----
00284 00282                 **********************************
00285 00283 F006 C6   55            LDB     #$55              %01010101
00286 00284 F008 108E 0000          LDY     #RAM1
00287 00285 F00C E7   A4    MCHK1   STB     ,Y                RAM1 TEST STARTS HERE
00288 00286 F00E E1   A4            CMPB    ,Y
00289 00287 F010 26   0A            BNE     MCHK11            IF WRITE AND READ DOES NOT MATCH, BAD MEMORY
00290 00288 F012 6F   A0            CLR     ,Y+
00291 00289 F014 108C 0800          CMPY    #RAM2             IS RAM1 DONE ?
00292 00290 F018 26   F2            BNE     MCHK1
00293 00291 F01A 86   01            LDA     #1
00294 00292 F01C 108E 0800  MCHK11  LDY     #RAM2             RAM2 TEST STARTS HERE.
00295 00293 F020 E7   A4    MCHK2   STB     ,Y
00296 00294 F022 E1   A4            CMPB    ,Y                IF READ AND WRITE NOT IDENTICAL, BAD MEM.
00297 00295 F024 26   0A            BNE     MCHK21
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00298 00296 F026 6F   A0              CLR    ,Y+
00299 00297 F028 108C 1000            CMPY   #RAM3               IS RAM2 DONE ?
00300 00298 F02C 26   F2              BNE    MCHK2
00301 00299 F02E 8B   02              ADDA   #$2                 IF GOOD MEM. SET BIT  2
00302 00300 F030 108E 1000    MCHK21  LDY    #RAM3               RAM3 TEST STARTS HERE.
00303 00301 F034 E7   A4      MCHK3   STB    ,Y
00304 00302 F036 E1   A4              CMPB   ,Y                  IF WRITE AND READ NOT IDENTICAL, BAD MEM.
00305 00303 F038 26   0A              BNE    MCHK31
00306 00304 F03A 6F   A0              CLR    ,Y+
00307 00305 F03C 108C 1800            CMPY   #RAM4               IS RAM3 DONE ?
00308 00306 F040 26   F2              BNE    MCHK3
00309 00307 F042 8B   04              ADDA   #$4                 IF GOOD MEM. SET BIT 3
00310 00308 F044 108E 1800    MCHK31  LDY    #RAM4               RAM4 TEST STARTS HERE
00311 00309 F048 E7   A4      MCHK4   STB    ,Y
00312 00310 F04A E1   A4              CMPB   ,Y                  IF WRITE AND READ NOT IDENTICAL,BAD MEM.
00313 00311 F04C 26   0A              BNE    MCHK41
00314 00312 F04E 6F   A0              CLR    ,Y+
00315 00313 F050 108C 2000            CMPY   #RAM5               IS RAM4 DONE ?
00316 00314 F054 26   F2              BNE    MCHK4
00317 00315 F056 8B   08              ADDA   #$8                 IF GOOD MEM, THEN SET BIT 4
00318 00316 F058 108E 2000    MCHK41  LDY    #RAM5               RAM5 STARTS HERE
00319 00317 F05C E7   A4      MCHK5   STB    ,Y
00320 00318 F05E E1   A4              CMPB   ,Y                  IF WRITE AND READ NOT IDENTICAL, BAD MEM.
00321 00319 F060 26   0A              BNE    MCHK51
00322 00320 F062 6F   A0              CLR    ,Y+
00323 00321 F064 108C 2800            CMPY   #RAM6               IS RAM5 DONE ?
00324 00322 F068 26   F2              BNE    MCHK5
00325 00323 F06A 8B   10              ADDA   #$10                IF GOOD MEM. THEN SET BIT 5
00326 00324 F06C 108E 2800    MCHK51  LDY    #RAM6               RAM6 TEST STARTS HERE.
00327 00325 F070 E7   A4      MCHK6   STB    ,Y
00328 00326 F072 E1   A4              CMPB   ,Y                  IF READ AND WRITE NOT IDENTICAL, BAD MEM.
00329 00327 F074 26   0A              BNE    MEMEND
00330 00328 F076 6F   A0              CLR    ,Y+
00331 00329 F078 108C 3000            CMPY   #RAM6+ROMSIZ        IS RAM6 DONE ?
00332 00330 F07C 26   F2              BNE    MCHK6
00333 00331 F07E 8B   20              ADDA   #$20                IF GOOD MEM. SET BIT 6
00334 00332 F080 97   FF      MEMEND  STA    MEMFLG
00335 00333                   *************
00336 00334                   ***    PIA INITIALIZATION
00337 00335                   *************
00338 00336 F082 7F   8009    RSTART  CLR    PIACA               WARM STARTUP POINT
00339 00337 F085 7F   800B            CLR    PIACB
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00340 00338 F088 86    FF              LDA    #$FF                 
00341 00339 F08A B7    8008            STA    PIADRA               PORT A AS OUTPUT
00342 00340 F08D B7    800A            STA    PIADRB               PORT B AS OUTPUT
00343 00341 F090 86    04              LDA    #$04
00344 00342 F092 B7    8009            STA    PIACA
00345 00343 F095 B7    800B            STA    PIACB
00346 00344 F098 7F    8008            CLR    PIAPA                SET PORT A LOW
00347 00345 F09B 7F    800A            CLR    PIAPB                SET PORT B LOW
00348 00346                       *********
00349 00347                       *   TIMER INITIALIZATION
00350 00348                       *       #3 TIMER : CONTINUOUS 16 BIT MODE,INTERNAL CLOCK
00351 00349                       *                  2400 BAUD RATE GENERATOR FOR IBM PC ACIA(2400*16)
00352 00350                       *                  TIME OUT INTERRUPT DISABLED.
00353 00351                       *       #2 TIMER : ONE SHOT 16 BIT MODE, INTERNAL CLOCK
00354 00352                       *                  TIME OUT INTERRUPT ENABLED.
00355 00353                       *                  NORMALLY 4 MS TIMEOUT
00356 00354                       *                  USED FOR SWITCH CONTROL ACIA TIME OUT CHECK
00357 00355                       *       #1 TIMER : ONE SHOT 16 BIT MODE,EXTERNAL CLOCK(16TIMES A/D
00358 00356                       *                  CLOCK) . INTR. DISABLED.
00359 00357                       *                  USED FOR CS CONTROL OF A/D
00360 00358                       *********
00361 00359 F09E 86    82              LDA    #$82                 CONT. 16BIT. INT.CLOCK. INTR. DISABL.
00362 00360 F0A0 B7    3800            STA    PTMC11               #3 TIMER CONTROL REG.
00363 00361 F0A3 8E    000C            LDX    #12
00364 00362 F0A6 BF    3806            STX    PTMM13               SET IBM PC BAUD RATE(2400 BAUD)
00365 00363 F0A9 86    E3              LDA    #TMON2
00366 00364 F0AB B7    3801            STA    PTMC12               SELECT CONTROL REG. #1 TIMER
00367 00365 F0AE 86    62              LDA    #TMON1               ONESHOT 16 B MODE,EXT. CLOCK,INTR. ENABLED
00368 00366 F0B0 B7    3800            STA    PTMC11               #1 TIMER CONTROL REG.
00369 00367                       ***********************
00370 00368 F0B3 86    81              LDA    #$81                 EXT. CLOCK,CONTINOUS,NO INTR,16BIT
00371 00369 F0B5 B7    2801            STA    PTMC22               TIMER2 #2 CONTROL
00372 00370 F0B8 86    82              LDA    #$82                 INT. CLK.CONT. 16 BIT, NO INTR.
00373 00371 F0BA B7    2800            STA    PTMC21               TIMER2 #1 CONTROL
00374 00372 F0BD 8E    F424            LDX    #62500               0.125 SEC TIMER VALUE
00375 00373 F0C0 BF    2802            STX    PTMM21               TIMER2 #1CLOCK  0.125 SEC. PULSE
00376 00374                       **********
00377 00375                       *
00378 00376                       *  ASYNCHRONOUS COMMUNICATION INTERFACE INITIALIZATION
00379 00377                       *      ACIA FOR A/D,D/A AND ON/OFF CONTROL : 8 BIT DATA,EVEN PARITY
00380 00378                       *            1 STOP BIT,/64 CLOCK
00381 00379                       *            RX ; RX INTR. ENABLED.(EXCEPT D/A)
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00382 00380                        *       TX ; NORMALLY TX INTR. ENABLED.
00383 00381                        *    A/D RX #2 FORMAT(FOR ADC 831) ; 8BIT,1STOP,NO PARITY,/64
00384 00382                        *       RX INTR. DISABLED.
00385 00383                        *    ACIA FOR IBM INTERFACE : 8 BIT DATA,NO PARITY,1 STOP BIT,
00386 00384                        *       /16 CLOCK
00387 00385                        *       RX :  INTR. ENABLED.
00388 00386                        *       TX ;  INTR. DISABLED
00389 00387                        *   ALL ACIA INTERRUPT IS VECTORED TO IRQ
00390 00388                        *
00391 00389                        **********
00392 00390 F0C3 86    03                 LDA     #MRST                MASTER RESET ALL ACIAS
00393 00391 F0C5 B7    6006               STA     SWSTS
00394 00392 F0C8 B7    5006               STA     DASTS
00395 00393 F0CB B7    4006               STA     ADSTS
00396 00394 F0CE B7    7006               STA     PCSTS
00397 00395 F0D1 86    95                 LDA     #PCRXON              8 BIT,N,1 STOP,/16,RX INTR. OFF,TX INTR. OFF
00398 00396 F0D3 B7    7006               STA     PCSTS                IBM PC SEREIAL COMMUNICATION FORMAT
00399 00397 F0D6 86    BA                 LDA     #RTXINT
00400 00398 F0D8 B7    6006               STA     SWSTS
00401 00399 F0DB 86    3A                 LDA     #TXINTR
00402 00400 F0DD B7    5006               STA     DASTS
00403 00401 F0E0 B7    4006               STA     ADSTS
00404 00402                        *******************************************
00405 00403                        * SENSE SWITCH CONTROL SET AND SET UP INITIAL CONTROL TABLE
00406 00404                        * FROM AS IS STATE( NO POWER CONTROL CHANGE AT INITIALIZATION.
00407 00405                        *******************************************
00408 00406 F0E3 7F    02E9               CLR     NFCH                 CHANNEL NUMBER STORAGE
00409 00407 F0E6 F6    6006       SETSW   LDB     SWSTS                CHECK TX REG. IF EMPTY
00410 00408 F0E9 C5    02                 BITB    #2
00411 00409 F0EB 27    F9                 BEQ     SETSW
00412 00410 F0ED C6    FF                 LDB     #$FF                 SEND OUT SW ADDRESS($FF)
00413 00411 F0EF F7    6007               STB     SWRTX
00414 00412 F0F2 F6    6006       SW2     LDB     SWSTS                TX REG. EMPTY ?
00415 00413 F0F5 C5    02                 BITB    #2
00416 00414 F0F7 27    F9                 BEQ     SW2
00417 00415 F0F9 C6    20                 LDB     #SWREAD              GET SWREAD COMMAND
00418 00416 F0FB FB    02E9               ADDB    NFCH                 ADD CHANNEL NUMBER
00419 00417 F0FE F7    6007               STB     SWRTX
00420 00418 F101 F6    6006       SWRX1   LDB     SWSTS                RX REG. FULL ?
00421 00419 F104 C5    01                 BITB    #1
00422 00420 F106 27    F9                 BEQ     SWRX1
00423 00421 F108 F6    6007               LDB     SWRTX                GET ADDRESS AND CONFIRM IT
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00424 00422 F10B C1    FF                CMPB   #$FF
00425 00423 F10D 26    D7                BNE    SETSW                IF ERROR, TRY AGAIN
00426 00424 F10F F6    6006     SWRX2    LDB    SWSTS                RX REG. FULL ?
00427 00425 F112 C5    01                BITB   #1
00428 00426 F114 27    F9                BEQ    SWRX2
00429 00427 F116 F6    6007              LDB    SWRTX                GET DATA
00430 00428 F119 B6    02E9              LDA    NFCH
00431 00429 F11C 8E    028D              LDX    #NFMTBL
00432 00430 F11F C4    40                ANDB   #$40
00433 00431 F121 27    02                BEQ    NFOFF
00434 00432 F123 6C    86                INC    A,X
00435 00433 F125 4C             NFOFF    INCA
00436 00434 F126 B7    02E9              STA    NFCH
00437 00435 F129 81    10                CMPA   #16                  ALL 16 CHANNEL DONE ?
00438 00436 F12B 25    B9                BLO    SETSW
00439 00437 F12D B6    0347              LDA    FMASK
00440 00438 F130 81    AA                CMPA   #$AA
00441 00439 F132 27    49                BEQ    RST1                 IF WARM STARTUP, SKIP D/A CLEARING
00442 00440                     ************ SW SET IS OVER AND CLEAR D/A CONTROL TO ZERO ********
00443 00441 F134 7F    02E4     CLRDA    CLR    DACH                 CLEAR CH. NO..STORAGE
00444 00442 F137 86    80                LDA    #$80                 GET ADDRESS COMMAND(+$80)
00445 00443 F139 B7    5007     CLRDAO   STA    DARTX                SEND CH. NO.
00446 00444 F13C B6    5006     CLRDA1   LDA    DASTS                WAIT UNTIL TX. REG. EMPTY
00447 00445 F13F 85    02                BITA   #2
00448 00446 F141 27    F9                BEQ    CLRDA1
00449 00447 F143 7F    5007              CLR    DARTX                SEND OUT NEXT CONTROL, SET TO NULL
00450 00448 F146 B6    5006     CLRDA2   LDA    DASTS                EAIT FOR TX. REG. EMPTY
00451 00449 F149 85    02                BITA   #2
00452 00450 F14B 27    F9                BEQ    CLRDA2
00453 00451 F14D 7C    02E4              INC    DACH                 NEXT CH.
00454 00452 F150 B6    02E4              LDA    DACH
00455 00453 F153 8B    80                ADDA   #$80
00456 00454 F155 81    98                CMPA   #$98                 ALL 24 CHANNEL DONE ?
00457 00455 F157 25    E0                BLO    CLRDAO
00458 00456                     **************************************************
00459 00457                     *        SEND OUT MEMORY TEST RESULT
00460 00458                     **************************************************
00461 00459 F159 F6    7006     MEMRPT   LDB    PCSTS                CHECK IF RX REG. FULL
00462 00460 F15C C5    01                BITB   #1
00463 00461 F15E 27    F9                BEQ    MEMRPT
00464 00462 F160 F6    7007              LDB    PCRTX
00465 00463 F163 C1    F7                CMPB   #TXCTL               TX REQUEST RECEIVED ?
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00466 00464 F165 26    F2                BNE    MEMRPT
00467 00465 F167 B6    7006      MEMTX1  LDA    PCSTS              IS TX REG. EMPTY ?
00468 00466 F16A 85    02                BITA   #2
00469 00467 F16C 27    F9                BEQ    MEMTX1
00470 00468 F16E F7    7007              STB    PCRTX              SEND OUT COMMAND BEFORE DATA
00471 00469 F171 B6    7006      MEMTX2  LDA    PCSTS              COMMAND OUT ?
00472 00470 F174 85    02                BITA   #2
00473 00471 F176 27    F9                BEQ    MEMTX2
00474 00472 F178 D6    FF                LDB    MEMFLG             SEND OUT TEST RESULT
00475 00473 F17A F7    7007              STB    PCRTX
00476 00474                      ***********  ALL D/A MASTER TABLE ARE SET TO FF (DISABLED) INITIALLY
00477 00475                      *********************************************************
00478 00476 F17D 5F              RST1    CLRB
00479 00477 F17E 86    FF                LDA    #$FF
00480 00478 F180 8E    025D              LDX    #DAC1
00481 00479 F183 A7    85        DAOFF   STA    B,X
00482 00480 F185 5C                      INCB
00483 00481 F186 C1    30                CMPB   #48
00484 00482 F188 25    F9                BLO    DAOFF
00485 00483                      *******************************
00486 00484                      *       START UP ROUTINE
00487 00485                      *
00488 00486                      *******************************
00489 00487 F18A B6    7006      MSTRT   LDA    PCSTS
00490 00488 F18D 85    01                BITA   #1
00491 00489 F18F 27    F9                BEQ    MSTRT
00492 00490 F191 B6    7007              LDA    PCRTX              GET START UP QUE FROM SLAVE
00493 00491 F194 81    F7                CMPA   #TXCTL
00494 00492 F196 26    F2                BNE    MSTRT
00495 00493 F198 86    80                LDA    #$80               A/D ADDRESS($00+$80)
00496 00494 F19A B7    4007              STA    ADRTX
00497 00495 F19D 7F    02E8              CLR    ADCH
00498 00496 F1A0 7F    02E4              CLR    DACH
00499 00497 F1A3 86    FF                LDA    #$FF               SEND DUMMY TO D/A
00500 00498 F1A5 B7    5007              STA    DARTX
00501 00499 F1A8 B7    6007              STA    SWRTX
00502 00500 F1AB 7F    02E1              CLR    SWRMOD
00503 00501 F1AE 7F    02E2              CLR    SWTMOD
00504 00502 F1B1 7F    0302              CLR    SWNEW
00505 00503 F1B4 7F    0301              CLR    SWCHG
00506 00504 F1B7 86    01                LDA    #1
00507 00505 F1B9 B7    02DF              STA    ADRMOD
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00508 00506 F1BC 8E   0FA0              LDX     #T04
00509 00507 F1BF BF   3804              STX     PTMM12
00510 00508 F1C2 8E   3E80              LDX     #T016
00511 00509 F1C5 BF   3802              STX     PTMM11
00512 00510 F1C8 8E   0000              LDX     #0
00513 00511 F1CB BF   02FB              STX     TXNUM
00514 00512 F1CE BF   02FD              STX     RXNUM
00515 00513 F1D1 33   8D 0EAB           LEAU    USTACK,PCR
00516 00514                     *****************************************
00517 00515                     *
00518 00516                     *        SUPERVISORY ROUTINE
00519 00517                     *****************************************
00520 00518 F1D5 1C   AF                ANDCC   #$AF                    REMOVE IRQ,FIRQ MASK
00521 00519 F1D7 B6   02FD      SUPERV  LDA     RXNUM                   GET RX BUFFER DATA COUNT
00522 00520 F1DA 81   03                CMPA    #3                      MORE THAN 3 BYTES ?
00523 00521 F1DC 25   F9                BLO     SUPERV
00524 00522 F1DE BE   0205              LDX     RXSTRT                  GET ONE BYTE
00525 00523 F1E1 A6   80                LDA     ,X+
00526 00524 F1E3 81   F7                CMPA    #TXCTL                  DATA REQUEST COMMAND ?
00527 00525 F1E5 26   0C                BNE     SUP1
00528 00526 F1E7 A6   80                LDA     ,X+
00529 00527 F1E9 A6   80                LDA     ,X+
00530 00528 F1EB BF   0205              STX     RXSTRT                  TAKE 3BYTE AND UPDATE POINTER
00531 00529 F1EE 7C   0346              INC     MOVFLG                  DATA MOVE FLAG SET
00532 00530 F1F1 20   6A                BRA     SETEND
00533 00531 F1F3 81   F9        SUP1    CMPA    #DACONT
00534 00532 F1F5 27   14                BEQ     DACSET
00535 00533 F1F7 81   F1                CMPA    #HENGTM                 HIGH ENERGY TIME SET UP ?
00536 00534 F1F9 27   26                BEQ     HIGH
00537 00535 F1FB 81   F2                CMPA    #LENGTM                 LOW ENERGY TIME SET UP ?
00538 00536 F1FD 27   3B                BEQ     LOW
00539 00537 F1FF 81   F3                CMPA    #OFFTM                  BEAM OFF TIME SET UP ?
00540 00538 F201 27   50                BEQ     SHUT
00541 00539 F203 7A   02FD              DEC     RXNUM                   IF NOT ANY OF ABOVE COMMAND,TRY
00542 00540 F206 BF   0205              STX     RXSTRT                  NEXT BYTE
00543 00541 F209 20   CC                BRA     SUPERV
00544 00542                     **************   D/A REFERENCE TABLE SET UP OR CHANGE  *********
00545 00543 F20B A6   80        DACSET  LDA     ,X+                     GET CHANNEL NO.
00546 00544 F20D E6   80                LDB     ,X+                     GET CONTROL VALUE
00547 00545 F20F BF   0205              STX     RXSTRT                  UPDATE POINTER
00548 00546 F212 108E 025D              LDY     #DAC1
00549 00547 F216 E7   A6                STB     A,Y
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00550 00548 F218 8E   0305               LDX    #DAINT1
00551 00549 F21B C6   01                 LDB    #1
00552 00550 F21D E7   86                 STB    A,X
00553 00551 F21F 20   3C                 BRA    SETEND
00554 00552                    ******** HIGH ,LOW ENERGY BEAM ON TIME SET UP  ****
00555 00553                    **
00556 00554 F221 A6   80       HIGH      LDA    ,X+                 MATERIAL #1 HIGH E TIME
00557 00555 F223 E6   80                 LDB    ,X+                 #2
00558 00556 F225 BF   0205               STX    RXSTRT              UPDATE POINTER
00559 00557 F228 81   01                 CMPA   #1
00560 00558 F22A 26   05                 BNE    H12
00561 00559 F22C F7   0213               STB    HITM1               INPUT DATA TIMES 8
00562 00560 F22F 20   2C                 BRA    SETEND
00563 00561 F231 81   02       H12       CMPA   #2
00564 00562 F233 26   28                 BNE    SETEND
00565 00563 F235 F7   0215               STB    HITM2
00566 00564 F238 20   23                 BRA    SETEND
00567 00565 F23A A6   80       LOW       LDA    ,X+                 MATERIAL #1 LOW ENERGY TIME
00568 00566 F23C E6   80                 LDB    ,X+                 #2
00569 00567 F23E BF   0205               STX    RXSTRT
00570 00568 F241 81   01                 CMPA   #1
00571 00569 F243 26   05                 BNE    LO2
00572 00570 F245 F7   0217               STB    LOTM1
00573 00571 F248 20   13                 BRA    SETEND
00574 00572 F24A 81   02       LO2       CMPA   #2
00575 00573 F24C 26   0F                 BNE    SETEND
00576 00574 F24E F7   0219               STB    LOTM2
00577 00575 F251 20   0A                 BRA    SETEND
00578 00576 F253 A6   80       SHUT      LDA    ,X+                 BEAM SWITCHING TIME
00579 00577 F255 E6   80                 LDB    ,X+
00580 00578 F257 BF   0205               STX    RXSTRT
00581 00579 F25A F7   021B               STB    SWTM
00582 00580 F25D 7A   02FD     SETEND    DEC    RXNUM               UPDATE DATA COUNTER
00583 00581 F260 7A   02FD               DEC    RXNUM
00584 00582 F263 7A   02FD               DEC    RXNUM
00585 00583 F266 12                      NOP
00586 00584 F267 16   FF6D     RSRVDR    LBRA   SUPERV
00587 00585 F26A 12                      NOP
00588 00586 F26B 16   FF69     KSWI3R    LBRA   SUPERV
00589 00587 F26E 12                      NOP
00590 00588 F26F 16   FF65     KSWI2R    LBRA   SUPERV
00591 00589 F272 12                      NOP
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```
00592 00590 F273 86   AA        KFIRQR  LDA    #$AA
00593 00591 F275 B7   0347              STA    FMASK                SET WARM STARTUP FLAG
00594 00592 F278 32   8D 0E75           LEAS   STACK,PCR            RESET STACK POINTER
00595 00593 F27C 8E   F082              LDX    #RSTART              SET RETURN ADDRESS
00596 00594 F27F 4F                     CLRA                        SET  CC
00597 00595 F280 34   12                PSHS   #$12                 STORE NEW PC AND CC ONTO STACK
00598 00596 F282 3B                     RTI
00599 00597 F283 16   FF51      KSWIR   LBRA   SUPERV
00600 00598 F286 12                     NOP
00601 00599 F287 16   FF4D      KNMIR   LBRA   SUPERV
00602 00600 F28A 12                     NOP
00603 00601 F28B 16   FF49              LBRA   SUPERV
00604 00602                     *********************************************
00605 00603                     *
00606 00604                     *       IRQ ROUTINE
00607 00605                     *         IRQ SOURCE  ; TIMER #2(SW TO),#3(A/D TO)
00608 00606                     *                       ON/OFF ACIA RX,TX
00609 00607                     *                       A/D ACIA TX,RX
00610 00608                     *                       IBM PC
00611 00609                     *********************************************
00612 00610 F800                       ORG    $F800
00613 00611 F800 B6   7006      KIRQR   LDA    PCSTS
00614 00612 F803 2B   25                BMI    PCTST
00615 00613 F805 B6   4006              LDA    ADSTS
00616 00614 F808 2B   79                BMI    ADTST
00617 00615 F80A B6   5006              LDA    DASTS
00618 00616 F80D 2B   0F                BMI    DATST
00619 00617 F80F B6   6006              LDA    SWSTS
00620 00618 F812 102B 0323              LBMI   SWTST
00621 00619 F816 B6   3801              LDA    PTMST1
00622 00620 F819 102B 0401              LBMI   PTMTST
00623 00621 F81D 3B                     RTI
00624 00622 F81E 86   1A        DATST   LDA    #NOINTR
00625 00623 F820 B7   5006              STA    DASTS
00626 00624 F823 B6   02E5              LDA    DAERR                IF FLAG=2 THEN SEND NEW CONTROL VALUE
00627 00625 F826 B7   5007              STA    DARTX
00628 00626 F829 3B                     RTI
00629 00627                     **************** PC RX, TX ROUTINE  ****************
00630 00628 F82A 85   01        PCTST   BITA   #1
00631 00629 F82C 26   24                BNE    PCRX
00632 00630 F82E 85   02                BITA   #2                   RX REG. FULL ?
00633 00631 F830 26   04                BNE    PCTX
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00634 00632 F832 B6   7007           LDA    PCRTX
00635 00633 F835 3B                  RTI
00636 00634 F836 B6   02FB    PCTX   LDA    TXNUM
00637 00635 F839 26   01             BNE    PCT1
00638 00636 F83B 3B                  RTI
00639 00637 F83C 7A   02FB    PCT1   DEC    TXNUM
00640 00638 F83F 26   05             BNE    PCT2
00641 00639 F841 86   95             LDA    #PCRXON
00642 00640 F843 B7   7006           STA    PCSTS
00643 00641 F846 BE   0207    PCT2   LDX    TXSTRT
00644 00642 F849 A6   80             LDA    ,X+
00645 00643 F84B B7   7007           STA    PCRTX
00646 00644 F84E BF   0207           STX    TXSTRT
00647 00645 F851 3B                  RTI
00648 00646 F852 B6   02FD    PCRX   LDA    RXNUM
00649 00647 F855 26   09             BNE    RXO
00650 00648 F857 8E   0081           LDX    #RXBUF
00651 00649 F85A BF   0209           STX    RXEND
00652 00650 F85D BF   0205           STX    RXSTRT
00653 00651 F860 B6   7007    RXO    LDA    PCRTX               GET RX REG. CONTENT
00654 00652 F863 BE   0209           LDX    RXEND
00655 00653 F866 A7   80             STA    ,X+                 STORE IT ON RX BUFFER
00656 00654 F868 8C   0101           CMPX   #RXBEND
00657 00655 F86B 25   03             BLO    RX1
00658 00656 F86D 8E   0081           LDX    #RXBUF
00659 00657 F870 BF   0209    RX1    STX    RXEND               UP DATA BUFFER POINTER
00660 00658 F873 B6   02FD           LDA    RXNUM               UPDATE DATA COUNT
00661 00659 F876 8B   01             ADDA   #1
00662 00660 F878 B7   02FD           STA    RXNUM
00663 00661 F87B 3B                  RTI
00664 00662 F87C B7   02EA    PCNG   STA    PCEFLG              STORE PC ERROR FLAG
00665 00663 F87F F6   7007           LDB    PCRTX
00666 00664 F882 3B                  RTI
00667 00665                   *****************  A/D RX ROUTINE  ****************
00668 00666 F883 85   01      ADTST  BITA   #1
00669 00667 F885 26   07             BNE    ADRRX
00670 00668 F887 85   02             BITA   #2
00671 00669 F889 1026 00CD           LBNE   ADTX
00672 00670 F88D 3B                  RTI
00673 00671 F88E B6   02DF    ADRRX  LDA    ADRMOD              MODE ?
00674 00672 F891 81   01             CMPA   #1
00675 00673 F893 27   0C             BEQ    ADM1                MODE1
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00676 00674 F895 81   02                 CMPA   #2
00677 00675 F897 27   1A                 BEQ    ADM2              MODE 2
00678 00676 F899 81   03                 CMPA   #3
00679 00677 F89B 27   45                 BEQ    ADM3              MODE 3
00680 00678 F89D B6   4007               LDA    ADRTX
00681 00679 F8A0 3B                      RTI
00682 00680 F8A1 B6   4007       ADM1    LDA    ADRTX
00683 00681 F8A4 86   02                 LDA    #2
00684 00682 F8A6 B7   02DF               STA    ADRMOD
00685 00683 F8A9 B6   02E8               LDA    ADCH
00686 00684 F8AC 81   1A                 CMPA   #26
00687 00685 F8AE 1027 022D               LBEQ   MOV1
00688 00686 F8B2 3B                      RTI
00689 00687 F8B3 B6   4007       ADM2    LDA    ADRTX             GET CH. NO.
00690 00688 F8B6 B7   02E4               STA    DACH              PRESERVE D/A CH. NO.
00691 00689 F8B9 B7   02FF               STA    ADNXT             STORE IT
00692 00690 F8BC BE   3804               LDX    PTMM12            PRESERVE #2 TIMER
00693 00691 F8BF 86   A1                 LDA    #TMRST            RESET ALL TIMERS
00694 00692 F8C1 B7   3800               STA    PTMC11
00695 00693 F8C4 BF   3804               STX    PTMM12            SET #2 TIMER TO PREVIOUS VALUE
00696 00694 F8C7 8E   000B               LDX    #CS               CS TIMER VALUE(10 CYCLES)
00697 00695 F8CA BF   3802               STX    PTMM11            TIMER #1 SET TO CS
00698 00696 F8CD 86   E0                 LDA    #CSON             SET CS TIMER ON
00699 00697 F8CF B7   3800               STA    PTMC11
00700 00698 F8D2 86   03                 LDA    #MRST             MASTER RESET
00701 00699 F8D4 B7   4006               STA    ADSTS
00702 00700 F8D7 86   96                 LDA    #ADRXON           A/D DEVICE FORMAT
00703 00701 F8D9 B7   4006               STA    ADSTS             CHNGE FORMAT
00704 00702 F8DC 86   03                 LDA    #3                UPDATE MODE
00705 00703 F8DE B7   02DF               STA    ADRMOD
00706 00704 F8E1 3B                      RTI
00707 00705 F8E2 BE   3804       ADM3    LDX    PTMM12            PRESERVE #2 TIMER
00708 00706 F8E5 86   A1                 LDA    #TMRST            MASTER RESET ALL TIMERS
00709 00707 F8E7 B7   3800               STA    PTMC11
00710 00708 F8EA BF   3804               STX    PTMM12            PRESERVE #2 TIMER TO PREVIOUS VALUE
00711 00709 F8ED 8E   3E80               LDX    #TO16
00712 00710 F8F0 BF   3802               STX    PTMM11            #1 TIMER 10 MS TIME OUT
00713 00711 F8F3 86   62                 LDA    #TMON1            TURN ON TIMER INTR.
00714 00712 F8F5 B7   3800               STA    PTMC11
00715 00713 F8F8 F6   4007               LDB    ADRTX
00716 00714 F8FB 86   03                 LDA    #MRST
00717 00715 F8FD B7   4006               STA    ADSTS             MASTER RESET
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00718 00716 F900 86   3A                LDA    #TXINTR            RX,TX BOTH INTR. ENABLED
00719 00717 F902 B7   4006              STA    ADSTS
00720 00718 F905 86   80                LDA    #$80               SEND OUT ADDRESS
00721 00719 F907 B7   4007              STA    ADRTX
00722 00720 F90A 86   01                LDA    #1                 UPDATE MODE
00723 00721 F90C B7   02DF              STA    ADRMOD
00724 00722                ******************** BIT TRANSPOSE ***********************
00725 00723 F90F 4F                     CLRA
00726 00724 F910 C5   80                BITB   #$80
00727 00725 F912 27   02                BEQ    B7
00728 00726 F914 8A   01                ORA    #1
00729 00727 F916 C5   40         B7     BITB   #$40
00730 00728 F918 27   02                BEQ    B6
00731 00729 F91A 8A   02                ORA    #2
00732 00730 F91C C5   20         B6     BITB   #$20
00733 00731 F91E 27   02                BEQ    B5
00734 00732 F920 8A   04                ORA    #4
00735 00733 F922 C5   10         B5     BITB   #$10
00736 00734 F924 27   02                BEQ    B4
00737 00735 F926 8A   08                ORA    #8
00738 00736 F928 C5   08         B4     BITB   #8
00739 00737 F92A 27   02                BEQ    B3
00740 00738 F92C 8A   10                ORA    #$10
00741 00739 F92E C5   04         B3     BITB   #4
00742 00740 F930 27   02                BEQ    B2
00743 00741 F932 8A   20                ORA    #$20
00744 00742 F934 C5   02         B2     BITB   #2
00745 00743 F936 27   02                BEQ    B1
00746 00744 F938 8A   40                ORA    #$40
00747 00745 F93A C5   01         B1     BITB   #1
00748 00746 F93C 27   02                BEQ    B0
00749 00747 F93E 8A   80                ORA    #$80
00750 00748 F940 7D   021B       B0     TST    SWTM
00751 00749 F943 27   0C                BEQ    STOR1
00752 00750 F945 F6   0345              LDB    BEAMOD
00753 00751 F948 C1   03                CMPB   #3
00754 00752 F94A 25   05                BLO    STOR1
00755 00753 F94C 8E   023D              LDX    #ADATA2
00756 00754 F94F 20   03                BRA    STOR2
00757 00755 F951 8E   021D       STOR1  LDX    #ADATA1
00758 00756 F954 F6   02E8       STOR2  LDB    ADCH
00759 00757 F957 A7   85                STA    B,X
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00760 00758 F959 3B                   RTI
00761 00759 F95A 7C    02E8    ADTX   INC     ADCH
00762 00760 F95D B6    02E8           LDA     ADCH
00763 00761 F960 81    20             CMPA    #32
00764 00762 F962 25    04             BLO     ADTX1
00765 00763 F964 4F                   CLRA
00766 00764 F965 7F    02E8           CLR     ADCH
00767 00765 F968 C6    9A      ADTX1  LDB     #RXINTR
00768 00766 F96A F7    4006           STB     ADSTS
00769 00767 F96D B7    4007           STA     ADRTX
00770 00768 F970 81    18             CMPA    #24
00771 00769 F972 25    05             BLO     DACHK
00772 00770 F974 81    1D             CMPA    #29
00773 00771 F976 27    33             BEQ     SWITCH
00774 00772 F978 3B                   RTI
00775 00773 F979 F6    0345    DACHK  LDB     BEAMOD
00776 00774 F97C C1    05             CMPB    #5
00777 00775 F97E 27    0D             BEQ     DACHK1
00778 00776 F980 C1    02             CMPB    #2
00779 00777 F982 25    09             BLO     DACHK1
00780 00778 F984 108E  031D           LDY     #DAINT2
00781 00779 F988 8E    0275           LDX     #DAC2
00782 00780 F98B 20    07             BRA     DACHK2
00783 00781 F98D 108E  0305    DACHK1 LDY     #DAINT1
00784 00782 F991 8E    025D           LDX     #DAC1
00785 00783 F994 6D    A6      DACHK2 TST     A,Y
00786 00784 F996 26    01             BNE     DACHK3
00787 00785 F998 3B                   RTI
00788 00786 F999 6F    A6      DACHK3 CLR     A,Y
00789 00787 F99B E6    86             LDB     A,X
00790 00788 F99D F7    02E5           STB     DAERR
00791 00789 F9A0 8A    80             ORA     #$80
00792 00790 F9A2 C6    3A             LDB     #TXINTR
00793 00791 F9A4 F7    5006           STB     DASTS
00794 00792 F9A7 B7    5007           STA     DARTX
00795 00793 F9AA 3B                   RTI
00796 00794                    ********** BEAM SWITCHING CONTROL   ***********************
00797 00795 F9AB 7C    02E7    SWITCH INC     BMCNT
00798 00796 F9AE B6    02E7           LDA     BMCNT
00799 00797 F9B1 F6    0345           LDB     BEAMOD
00800 00798 F9B4 27    17             BEQ     BMO                MODEO, LOW E #1
00801 00799 F9B6 C1    01             CMPB    #1
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00802 00800 F9B8 27   30              BEQ    BM1                 MODE1, HIGH E #1
00803 00801 F9BA C1   02              CMPB   #2
00804 00802 F9BC 27   70              BEQ    BM2                 MODE2, NO BEAM
00805 00803 F9BE C1   03              CMPB   #3
00806 00804 F9C0 1027 0097            LBEQ   BM3                 MODE3, LOW E #2
00807 00805 F9C4 C1   04              CMPB   #4
00808 00806 F9C6 1027 00A8            LBEQ   BM4                 MODE4, HIGH E #2
00809 00807 F9CA 16   00E0            LBRA   BM5                 MODE5, NO BEAM
00810 00808                  *******  BEAM MODE 0 ------ LOW ENERGY #1 MATERIAL
00811 00809 F9CD 7D   0217   BM0      TST    LOTM1
00812 00810 F9D0 27   01              BEQ    BM01                TIMER 0 ?
00813 00811 F9D2 3B                   RTI
00814 00812 F9D3 7F   02E7   BM01     CLR    BMCNT
00815 00813 F9D6 7D   0213            TST    HITM1
00816 00814 F9D9 27   09              BEQ    BM02
00817 00815 F9DB 7C   0345            INC    BEAMOD
00818 00816 F9DE 86   FF              LDA    #$FF
00819 00817 F9E0 B7   800A            STA    PIAPB
00820 00818 F9E3 3B                   RTI
00821 00819 F9E4 7D   021B   BM02     TST    SWTM
00822 00820 F9E7 26   16              BNE    BM12
00823 00821 F9E9 3B                   RTI
00824 00822                  ************ MODE 1 , HIGH ENERGY MATERIAL #1
00825 00823 F9EA B1   0213   BM1      CMPA   HITM1
00826 00824 F9ED 22   01              BHI    BM11
00827 00825 F9EF 3B                   RTI
00828 00826 F9F0 7F   02E7   BM11     CLR    BMCNT
00829 00827 F9F3 7F   800A            CLR    PIAPB
00830 00828 F9F6 7D   021B            TST    SWTM
00831 00829 F9F9 26   04              BNE    BM12
00832 00830 F9FB 7F   0345            CLR    BEAMOD
00833 00831 F9FE 3B                   RTI
00834 00832 F9FF 86   02     BM12     LDA    #2                  SET NEXT MODE
00835 00833 FA01 B7   0345            STA    BEAMOD
00836 00834 FA04 8E   0275            LDX    #DAC2               GET CONTROL TABLE
00837 00835 FA07 A6   01              LDA    1,X                 STORE BEAM ENERGY ON TEMPO. LOCATION
00838 00836 FA09 B7   02E6            STA    BMENG
00839 00837 FA0C 6F   01              CLR    1,X                 SET ENERGY 0
00840 00838 FA0E 108E 031D            LDY    #DAINT2
00841 00839 FA12 C6   01              LDB    #1
00842 00840 FA14 E7   21              STB    1,Y                 BEAM ENERGY
00843 00841 FA16 E7   28              STB    8,Y                 MAGNET
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00844 00842 FA18 E7   2A                 STB    10,Y
00845 00843 FA1A E7   2B                 STB    11,Y
00846 00844 FA1C E7   2C                 STB    12,Y
00847 00845 FA1E E7   2D                 STB    13,Y
00848 00846 FA20 E7   2E                 STB    14,Y
00849 00847 FA22 E7   2F                 STB    15,Y
00850 00848 FA24 E7   A8 10              STB    16,Y
00851 00849 FA27 E7   A8 11              STB    17,Y
00852 00850 FA2A E7   A8 15              STB    21,Y               FOCUS
00853 00851 FA2D 3B                      RTI
00854 00852                    ********* MODE2 .  NO BEAM CYCLE      *****************
00855 00853 FA2E B1   021B       BM2     CMPA   SWTM
00856 00854 FA31 22   01                 BHI    BM21
00857 00855 FA33 3B                      RTI
00858 00856 FA34 7F   02E7       BM21    CLR    BMCNT
00859 00857 FA37 B6   02E6               LDA    BMENG
00860 00858 FA3A 8E   0275               LDX    #DAC2
00861 00859 FA3D 108E 031D               LDY    #DAINT2
00862 00860 FA41 A7   01                 STA    1,X
00863 00861 FA43 A7   21                 STA    1,Y
00864 00862 FA45 7D   0219               TST    LOTM2
00865 00863 FA48 27   04                 BEQ    BM22
00866 00864 FA4A 7C   0345               INC    BEAMOD
00867 00865 FA4D 3B                      RTI
00868 00866 FA4E 7D   0215       BM22    TST    HITM2
00869 00867 FA51 27   01                 BEQ    BM23
00870 00868 FA53 3B                      RTI
00871 00869 FA54 7F   0345       BM23    CLR    BEAMOD
00872 00870 FA57 7F   021B               CLR    SWTM
00873 00871 FA5A 3B                      RTI
00874 00872                    ***** MODE 3 , LOW ENERGY CYCLE FOR MATERIAL #2  *************
00875 00873 FA5B 7D   0219       BM3     TST    LOTM2
00876 00874 FA5E 27   01                 BEQ    BM31
00877 00875 FA60 3B                      RTI
00878 00876 FA61 7F   02E7       BM31    CLR    BMCNT
00879 00877 FA64 7D   0215               TST    HITM2
00880 00878 FA67 27   15                 BEQ    BM42
00881 00879 FA69 7C   0345               INC    BEAMOD
00882 00880 FA6C 86   FF                 LDA    #$FF
00883 00881 FA6E B7   800A               STA    PIAPB
00884 00882 FA71 3B                      RTI
00885 00883                    ******** MODE 4, HIGH ENERGY CYCLE FOR MATERIAL #2
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00886 00884 FA72 B1   0215      BM4     CMPA   HITM2
00887 00885 FA75 22   01                BHI    BM41
00888 00886 FA77 3B                     RTI
00889 00887 FA78 7F   02E7      BM41    CLR    BMCNT
00890 00888 FA7B 7F   800A              CLR    PIAPB
00891 00889 FA7E 8E   025D      BM42    LDX    #DAC1
00892 00890 FA81 108E 0305              LDY    #DAINT1
00893 00891 FA85 A6   01                LDA    1,X
00894 00892 FA87 B7   02E6              STA    BMENG
00895 00893 FA8A 6F   01                CLR    1,X
00896 00894 FA8C C6   01                LDB    #1
00897 00895 FA8E E7   21                STB    1,Y
00898 00896 FA90 E7   28                STB    8,Y
00899 00897 FA92 E7   2A                STB    10,Y
00900 00898 FA94 E7   2B                STB    11,Y
00901 00899 FA96 E7   2C                STB    12,Y
00902 00900 FA98 E7   2D                STB    13,Y
00903 00901 FA9A E7   2E                STB    14,Y
00904 00902 FA9C E7   2F                STB    15,Y
00905 00903 FA9E E7   A8 10             STB    16,Y
00906 00904 FAA1 E7   A8 11             STB    17,Y
00907 00905 FAA4 E7   A8 15             STB    21,Y
00908 00906 FAA7 86   05                LDA    #5
00909 00907 FAA9 B7   0345              STA    BEAMOD
00910 00908 FAAC 3B                     RTI
00911 00909                     *********** MODE 5, NO BEAM CYCLE  ******************
00912 00910 FAAD B1   021B      BM5     CMPA   SWTM
00913 00911 FAB0 22   01                BHI    BM51
00914 00912 FAB2 3B                     RTI
00915 00913 FAB3 7F   02E7      BM51    CLR    BMCNT
00916 00914 FAB6 8E   025D              LDX    #DAC1
00917 00915 FAB9 108E 0305              LDY    #DAINT1
00918 00916 FABD B6   02E6              LDA    BMENG
00919 00917 FAC0 A7   01                STA    1,X
00920 00918 FAC2 A7   21                STA    1,Y
00921 00919 FAC4 7D   0217              TST    LOTM1
00922 00920 FAC7 27   04                BEQ    BM52
00923 00921 FAC9 7F   0345              CLR    BEAMOD
00924 00922 FACC 3B                     RTI
00925 00923 FACD 7D   0213      BM52    TST    HITM1
00926 00924 FAD0 1027 FF1C              LBEQ   BM11
00927 00925 FAD4 86   01                LDA    #1
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00928 00926 FAD6 B7   0345                STA    BEAMOD
00929 00927 FAD9 86   FF                  LDA    #$FF
00930 00928 FADB B7   800A                STA    PIAPB
00931 00929 FADE 3B                       RTI
00932 00930                        ****** DATA MOVE ROUTINE STARTS HERE  ******************
00933 00931 FADF 7D   0346         MOV1   TST    MOVFLG
00934 00932 FAE2 26   01                  BNE    MOV2
00935 00933 FAE4 3B                       RTI
00936 00934 FAE5 7D   02FB         MOV2   TST    TXNUM
00937 00935 FAE8 27   01                  BEQ    MOV3
00938 00936 FAEA 3B                       RTI
00939 00937 FAEB 86   B5           MOV3   LDA    #PCRTON
00940 00938 FAED B7   7006                STA    PCSTS
00941 00939 FAF0 4F                       CLRA
00942 00940 FAF1 7F   0346                CLR    MOVFLG
00943 00941 FAF4 8E   0103                LDX    #TXBUF
00944 00942 FAF7 BF   0207                STX    TXSTRT
00945 00943 FAFA C6   F0                  LDB    #FIRST
00946 00944 FAFC E7   80                  STB    ,X+
00947 00945 FAFE C6   F1                  LDB    #SECOND
00948 00946 FB00 E7   80                  STB    ,X+
00949 00947 FB02 F6   0345                LDB    BEAMOD
00950 00948 FB05 E7   80                  STB    ,X+
00951 00949 FB07 C1   03                  CMPB   #3
00952 00950 FB09 25   06                  BLO    MOV4
00953 00951 FB0B 108E 023D                LDY    #ADATA2
00954 00952 FB0F 20   04                  BRA    MOV5
00955 00953 FB11 108E 021D         MOV4   LDY    #ADATA1
00956 00954 FB15 E6   A0           MOV5   LDB    ,Y+
00957 00955 FB17 E7   80                  STB    ,X+
00958 00956 FB19 4C                       INCA
00959 00957 FB1A 81   20                  CMPA   #32
00960 00958 FB1C 25   F7                  BLO    MOV5
00961 00959 FB1E 108E 02EB                LDY    #NFLIST
00962 00960 FB22 4F                       CLRA
00963 00961 FB23 E6   A0           MOV6   LDB    ,Y+
00964 00962 FB25 E7   80                  STB    ,X+
00965 00963 FB27 4C                       INCA
00966 00964 FB28 81   10                  CMPA   #16
00967 00965 FB2A 25   F7                  BLO    MOV6
00968 00966 FB2C 86   34                  LDA    #52
00969 00967 FB2E B7   02FB                STA    TXNUM
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00970 00968 FB31 C6   F2                LDB    #LAST
00971 00969 FB33 E7   80                STB    ,X+
00972 00970 FB35 BF   020B              STX    TXEND
00973 00971 FB38 3B                     RTI
00974 00972                     ****
00975 00973                     *************  ON/OFF SWITCH CONTROL IRQ ROUTINE  *********
00976 00974                     ****
00977 00975 FB39 BE   3804      SWTST   LDX    PTMM12             RESET TIMER #2
00978 00976 FB3C 85   01                BITA   #1
00979 00977 FB3E 26   08                BNE    SWRX3
00980 00978 FB40 85   02                BITA   #2
00981 00979 FB42 1026 0093              LBNE   SWTX
00982 00980 FB46 20   7B                BRA    SWERR
00983 00981 FB48 8E   028D      SWRX3   LDX    #NFMTBL            GET REFERENCE TABLE ADDRESS
00984 00982 FB4B B6   02E1              LDA    SWRMOD             GET MODE
00985 00983 FB4E 26   0B                BNE    SWRX4
00986 00984 FB50 B6   6007              LDA    SWRTX
00987 00985 FB53 81   FF                CMPA   #$FF               IS ADDRESS $FF ?
00988 00986 FB55 26   6C                BNE    SWERR              IF NOT, ERROR
00989 00987 FB57 7C   02E1              INC    SWRMOD
00990 00988 FB5A 3B                     RTI
00991 00989 FB5B 7F   02E1      SWRX4   CLR    SWRMOD             UPDATE MODE
00992 00990 FB5E B6   6007              LDA    SWRTX              GET DATA
00993 00991 FB61 1F   89                TFR    A,B
00994 00992 FB63 84   0F                ANDA   #$0F               GET CHANNEL NO.
00995 00993 FB65 B7   0300              STA    TEMPO
00996 00994 FB68 C4   40                ANDB   #$40               GET ON/OFF STATUS(BIT 6)
00997 00995 FB6A 27   1D                BEQ    RXOFF
00998 00996 FB6C 6D   86                TST    A,X                TEST REFERENCE
00999 00997 FB6E 27   09                BEQ    SWRX5
01000 00998 FB70 8E   02EB              LDX    #NFLIST
01001 00999 FB73 C6   01                LDB    #1
01002 01000 FB75 E7   86                STB    A,X
01003 01001 FB77 20   2B                BRA    SWNXT
01004 01002 FB79 C6   00        SWRX5   LDB    #SWOFF             SET OFF COMMAND
01005 01003 FB7B FB   0300              ADDB   TEMPO
01006 01004 FB7E F7   0302              STB    SWNEW              SET FLAG
01007 01005 FB81 7C   0301              INC    SWCHG
01008 01006 FB84 B6   0300              LDA    TEMPO
01009 01007 FB87 20   24                BRA    SWNXT1
01010 01008 FB89 6D   86        RXOFF   TST    A,X                TEST REFERENCE
01011 01009 FB8B 26   07                BNE    SWRX6
```

```
01012 01010 FB8D 8E   02EB            LDX   #NFLIST
01013 01011 FB90 6F   86              CLR   A,X
01014 01012 FB92 20   10              BRA   SWNXT
01015 01013 FB94 C6   40      SWRX6   LDB   #SWON           SET ON COMMAND
01016 01014 FB96 FB   0300            ADDB  TEMPO
01017 01015 FB99 F7   0302            STB   SWNEW           SET FLAG
01018 01016 FB9C 7C   0301            INC   SWCHG
01019 01017 FB9F B6   0300            LDA   TEMPO
01020 01018 FBA2 20   09              BRA   SWNXT1
01021 01019 FBA4 B6   02E9    SWNXT   LDA   NFCH
01022 01020 FBA7 4C                   INCA
01023 01021 FBA8 81   10              CMPA  #16
01024 01022 FBAA 25   01              BLO   SWNXT1
01025 01023 FBAC 4F                   CLRA
01026 01024 FBAD B7   02E9    SWNXT1  STA   NFCH
01027 01025 FBB0 7D   6007            TST   SWRTX
01028 01026 FBB3 2A   0C              BPL   SWNXT2
01029 01027 FBB5 27   0A              BEQ   SWNXT2
01030 01028 FBB7 8E   02EB            LDX   #NFLIST
01031 01029 FBBA B6   0300            LDA   TEMPO
01032 01030 FBBD C6   FF              LDB   #$FF
01033 01031 FBBF E7   86              STB   A,X
01034 01032 FBC1 12           SWNXT2  NOP
01035 01033 FBC2 3B                   RTI
01036 01034 FBC3 86   03      SWERR   LDA   #MRST
01037 01035 FBC5 B7   6006            STA   SWSTS
01038 01036 FBC8 86   BA              LDA   #RTXINT
01039 01037 FBCA B7   6006            STA   SWSTS
01040 01038 FBCD 86   FF              LDA   #$FF
01041 01039 FBCF B7   6007            STA   SWRTX
01042 01040 FBD2 7F   02E2            CLR   SWTMOD
01043 01041 FBD5 7F   02E1            CLR   SWRMOD
01044 01042 FBD8 3B                   RTI
01045 01043 FBD9 8E   0FA0    SWTX    LDX   #T04            RESET TIMER #2
01046 01044 FBDC BF   3804            STX   PTMM12
01047 01045 FBDF B6   02E2            LDA   SWTMOD          GET MODE
01048 01046 FBE2 27   06              BEQ   SWT0
01049 01047 FBE4 81   01              CMPA  #1
01050 01048 FBE6 27   23              BEQ   SWT1
01051 01049 FBE8 20   28              BRA   SWT2
01052 01050 FBEA 7D   0301    SWT0    TST   SWCHG           MODE 0, SW FLAG SET ?
01053 01051 FBED 27   10              BEQ   NOCHNG          IF NOT, NO CHANGE OF CONTROL
```

```
01054 01052 FBEF B6   0302             LDA    SWNEW            GET CONTROL WORD
01055 01053 FBF2 B7   6007             STA    SWRTX            SEND OUT CONTROL
01056 01054 FBF5 7F   0302             CLR    SWNEW            RESET FLAG
01057 01055 FBF8 7F   0301             CLR    SWCHG
01058 01056 FBFB 7C   02E2             INC    SWTMOD           UPDATE MODE
01059 01057 FBFE 3B                    RTI
01060 01058 FBFF 86   20      NOCHNG   LDA    #SWREAD          SEND READ STATUS COMMAND
01061 01059 FC01 BB   02E9             ADDA   NFCH
01062 01060 FC04 B7   6007             STA    SWRTX
01063 01061 FC07 7C   02E2             INC    SWTMOD           UPDATE MODE
01064 01062 FC0A 3B                    RTI
01065 01063 FC0B 7F   6007    SWT1     CLR    SWRTX            SEND DUMMY 1
01066 01064 FC0E 7C   02E2             INC    SWTMOD
01067 01065 FC11 3B                    RTI
01068 01066 FC12 86   FF      SWT2     LDA    #$FF             SEND OUT ADDRESS(FF)
01069 01067 FC14 B7   6007             STA    SWRTX
01070 01068 FC17 7F   02E2             CLR    SWTMOD
01071 01069 FC1A 7F   02E1             CLR    SWRMOD
01072 01070 FC1D 3B                    RTI
01073 01071                   **************************
01074 01072                   * TIME OUT SUBROUTINE
01075 01073                   **************************
01076 01074 FC1E 85   01      PTMTST   BITA   #1
01077 01075 FC20 26   32               BNE    ADTOUT
01078 01076 FC22 85   02               BITA   #2
01079 01077 FC24 26   01               BNE    SWTOUT
01080 01078 FC26 3B                    RTI
01081 01079 FC27 8E   0FA0    SWTOUT   LDX    #T04             TIME OUT 4 MSEC. ONESHOT
01082 01080 FC2A BF   3804             STX    PTMM12           TIMER #2
01083 01081 FC2D 86   03               LDA    #MRST            MASTER RESET SWACIA
01084 01082 FC2F B7   6006             STA    SWSTS
01085 01083 FC32 86   BA               LDA    #RTXINT          FORMAT RTX INTR.
01086 01084 FC34 B7   6006             STA    SWSTS
01087 01085 FC37 7F   02E2             CLR    SWTMOD
01088 01086 FC3A 7F   02E1             CLR    SWRMOD
01089 01087 FC3D 86   FF               LDA    #$FF             SEND OUT DEVICE ADDRESS($FF)
01090 01088 FC3F B7   6007             STA    SWRTX
01091 01089 FC42 F6   02E9             LDB    NFCH             GET CURRENT CHANNEL NO.
01092 01090 FC45 8E   02EB             LDX    #NFLIST
01093 01091 FC48 A7   85               STA    B,X              ERROR CHANNEL FLAG SET
01094 01092 FC4A 5C                    INCB                    NEXT CHANNEL
01095 01093 FC4B C1   10               CMPB   #16
```

```
01096 01094  C4D 25    01                BLO     SWTEND
01097 01095 FC4F 5F                        CLRB
01098 01096 FC50 F7    02E9      SWTEND    STB     NFCH                    CHANNEL UPDATED
01099 01097 FC53 3B                        RTI
01100 01098 FC54 BE    3804      ADTOUT    LDX     PTMM12                  RETRIVE #2 TIMER CONTENT
01101 01099 FC57 86    A1                  LDA     #TMRST                  RESET TIMERS
01102 01100 FC59 B7    3800                STA     PTMC11
01103 01101 FC5C BF    3804                STX     PTMM12
01104 01102 FC5F 8E    3E80                LDX     #TO16
01105 01103 FC62 BF    3802                STX     PTMM11
01106 01104 FC65 86    62                  LDA     #TMON1                  TURN ON TIMER INTER.
01107 01105 FC67 B7    3800                STA     PTMC11
01108 01106 FC6A F6    0345                LDB     BEAMOD
01109 01107 FC6D C1    02                  CMPB    #2
01110 01108 FC6F 22    05                  BHI     ADTO1
01111 01109 FC71 8E    021D                LDX     #ADATA1
01112 01110 FC74 20    03                  BRA     ADTO2
01113 01111 FC76 8E    023D      ADTO1     LDX     #ADATA2
01114 01112 FC79 C6    FF        ADTO2     LDB     #$FF
01115 01113 FC7B B6    02E8                LDA     ADCH                    GET ERROR CHANNEL NUMBER
01116 01114 FC7E E7    86                  STB     A,X
01117 01115 FC80 86    03                  LDA     #MRST
01118 01116 FC82 B7    4006                STA     ADSTS
01119 01117 FC85 86    3A                  LDA     #TXINTR                 IF ERROR,RESET FORMAT AND START AGAIN
01120 01118 FC87 B7    4006                STA     ADSTS
01121 01119 FC8A 86    80                  LDA     #$80                    SEND OUT ADDRESS
01122 01120 FC8C B7    4007                STA     ADRTX
01123 01121 FC8F 86    01                  LDA     #1
01124 01122 FC91 B7    02DF                STA     ADRMOD                  RESET RX MODE
01125 01123 FC94 3B                        RTI
01126 01124 FC95 12                        NOP
01127 01125 FC96 12                        NOP
01128 01126 FC97 12                        NOP
01129 01127 FC98 16    F53C                LBRA    SUPERV
01130 01128 FFF0                           ORG     ROM1+ROMSIZ-16
01131 01129 FFF0       F267                FDB     RSRVDR
01132 01130 FFF2       F26B                FDB     KSWI3R
01133 01131 FFF4       F26F                FDB     KSWI2R
01134 01132 FFF6       F273                FDB     KFIRQR
01135 01133 FFF8       F800                FDB     KIRQR
01136 01134 FFFA       F283                FDB     KSWIR
01137 01135 FFFC       F287                FDB     KNMIR
```

```
01138 01136 FFFE      F000              FDB    KRESET
01139 01137                             END
TOTAL ERRORS:   0
TOTAL WARNINGS:   0


SYMBOL TABLE


 ACIAAD 4006  ACIADA 5006  ACIAPC 7006  ACIASW 6006  ADATA1 021D
 ADATA2 023D  ADCH   02E8  ADM1   F8A1  ADM2   F8B3  ADM3   F8E2
 ADMODE 02DD  ADNXT  02FF  ADRMOD 02DF  ADRRX  F88E  ADRTON 00B6
 ADRTX  4007  ADRXOF 0016  ADRXON 0096  ADSTS  4006  ADTO1  FC76
 ADTO2  FC79  ADTMOD 02E0  ADTOUT FC54  ADTST  F883  ADTX   F95A
 ADTX1  F968  ADUAL  0210  ADUP   02E3  ANODE  0004  B0     F940
 B1     F93A  B2     F934  B3     F92E  B4     F928  B5     F922
 B6     F91C  B7     F916  BASEPG 00FB  BEAMOD 0345  BM0    F9CD
 BM01   F9D3  BM02   F9E4  BM1    F9EA  BM11   F9F0  BM12   F9FF
 BM2    FA2E  BM21   FA34  BM22   FA4E  BM23   FA54  BM3    FA5B
 BM31   FA61  BM4    FA72  BM41   FA78  BM42   FA7E  BM5    FAAD
 BM51   FAB3  BM52   FACD  BMCNT  02E7  BMENG  02E6  CLRDA  F134
 CLRDA0 F139  CLRDA1 F13C  CLRDA2 F146  CS     000B  CSOFF  0020
 CSON   00E0  DABAD  00F5  DAC1   025D  DAC2   0275  DACH   02E4
 DACHK  F979  DACHK1 F98D  DACHK2 F994  DACHK3 F999  DACONT 00F9
 DACSET F20B  DAERR  02E5  DAINT1 0305  DAINT2 031D  DAOFF  F183
 DARTX  5007  DASTS  5006  DATEMP 029D  DATST  F81E  DDUAL  0211
 DECEL  000A  DPS    0003  DPT    0004  DUALST 0212  FFIL   0002
 FFILSW 000C  FIRST  00F0  FMASK  0347  FOCUS  0005  GASP   0018
 GATE   0006  GHPRP  0007  H12    F231  HDEF   0008  HENGTM 00F1
 HIGH   F221  HITM1  0213  HITM2  0215  HIVOLT 0003  HIVSW  000F
 HTRTRB 0008  IBEAM  0007  IQCNT  0303  IQMAP  0304  KFIRQR F273
 KIRQR  F800  KNMIR  F287  KRESET F000  KSWI2R F26F  KSWI3R F26B
 KSWIR  F283  LAST   00F2  LENGTM 00F2  LO2    F24A  LOTM1  0217
 LOTM2  0219  LOW    F23A  MAGNET 000A  MAGSW  0009  MCHK1  F00C
 MCHK11 F01C  MCHK2  F020  MCHK21 F030  MCHK3  F034  MCHK31 F044
 MCHK4  F048  MCHK41 F058  MCHK5  F05C  MCHK51 F06C  MCHK6  F070
 MEMEND F080  MEMFLG 00FF  MEMRPT F159  MEMTX1 F167  MEMTX2 F171
 MOV1   FADF  MOV2   FAE5  MOV3   FAEB  MOV4   FB11  MOV5   FB15
 MOV6   FB23  MOVFLG 0346  MRST   0003  MSTRT  F18A  MTABLE 00F0
 NFCH   02E9  NFINT  0335  NFLIST 02EB  NFMODE 02DE  NFMTBL 028D
 NFOFF  F125  NOCHNG FBFF  NOINTR 001A  OFFTM  00F3  PCBAD  00F6
 PCEFLG 02EA  PCEROR 020F  PCNG   F87C  PCRTON 00B5  PCRTX  7007
```

```
PCRX    F852  PCRXON 0095  PCSTS  7006  PCT1   F83C  PCT2   F846
PCTST   F82A  PCTX   F836  PIA    8008  PIACA  8009  PIACB  800B
PIADRA  8008  PIADRB 800A  PIAPA  8008  PIAPB  800A  PTM1   3800
PTM2    2800  PTMC11 3800  PTMC12 3801  PTMC21 2800  PTMC22 2801
PTMM11  3802  PTMM12 3804  PTMM13 3806  PTMM21 2802  PTMM22 2804
PTMM23  2806  PTMST1 3801  PTMST2 2801  PTMTST FC1E  RAM1   0000
RAM2    0800  RAM3   1000  RAM4   1800  RAM5   2000  RAM6   2800
ROM1    F800  ROM2   F000  ROM3   E800  ROM4   E000  ROM5   D800
ROM6    D000  ROMSIZ 0800  RPS    0001  RPT    0002  RSRVDR F267
RST1    F17D  RSTART F082  RTXINT 00BA  RXO    F860  RX1    F870
RXBEND  0101  RXBUF  0081  RXEND  0209  RXINTR 009A  RXNUM  02FD
RXOFF   FB89  RXSTRT 0205  SCHMBP 0014  SECOND 00F1  SETEND F25D
SETSW   F0E6  SFIL   0001  SFILSW 000B  SFLP   0016  SHUT   F253
SPRSW   000D  STACK  00F1  STOR1  F951  STOR2  F954  SUP1   F1F3
SUPERV  F1D7  SW2    F0F2  SWCHG  0301  SWERR  FBC3  SWITCH F9AB
SWNEW   0302  SWNXT  FBA4  SWNXT1 FBAD  SWNXT2 FBC1  SWOFF  0000
SWON    0040  SWREAD 0020  SWRMOD 02E1  SWRTX  6007  SWRX1  F101
SWRX2   F10F  SWRX3  FB48  SWRX4  FB5B  SWRX5  FB79  SWRX6  FB94
SWSTS   6006  SWTO   FBEA  SWT1   FC0B  SWT2   FC12  SWTEND FC50
SWTM    021B  SWTMOD 02E2  SWTOUT FC27  SWTST  FB39  SWTX   FBD9
TCHMBP  0015  TEMPO  0300  TFLP   0017  TMOFF1 0022  TMOFF2 00A3
TMON1   0062  TMON2  00E3  TMRST  00A1  TO1    03E8  TO10   2710
TO13    32C8  TO16   3E80  TO3    0BB8  TO4    0FA0  TO6    1770
TPRSW   000E  TURBO  0005  TXBEND 0203  TXBUF  0103  TXCTL  00F7
TXEND   020B  TXINTR 003A  TXNUM  02FB  TXOFF  020D  TXSTRT 0207
USTACK  0080  VBEAM  0006  VDEF   0009  VECTAB 00FD  VELBAL 0012
VELL1   000F  VELL2  0010  VELL3  0011  VELM   0013  VELR1  000C
VELR2   000D  VELR3  000E  VELV   000B  WORKPG 0000
```

# XII. APPENDIX II

## MASTER COMPUTER ION BEAM DEPOSITION ROUTINE

```
1 REM---- ******************************************************
2 REM----
3 REM--------- SEQUENTIAL ION BEAM DEPOSITION SYSTEM
4 REM--------- OPERATING ROUTINE
5 REM---------
6 REM---------
7 REM--------- Written by Jaeshin Ahn
8 REM--------- Dept. of Electrical Engineering
9 REM--------- University of Alberta
10 REM-------- January, 1984
11 REM--------
20 REM---- ********************************************************
40 REM----
60 REM----
80 REM---- The master program to run low energy ion beam deposition system
100 REM---- in corporation with slave computer which is equipped with
120 REM---- 32 A/D, 24 D/A and 16 AC load controllers.
140 REM---- The communication between slave and master is coneected via serial
160 REM---- line (COM1).
180 REM----
200 REM----
300 REM----
320 REM---- revision : March,1985
340 REM---- - up/down unit step change display on both pages for common channels
360 REM---- - common channel reference change display on both screen pagess.
380 REM---- - initial screen set-up includes s-fil. high resolution controls
400 REM---- - dosage accumulation display resolution increased to uC level
420 REM---- - after completion of deposition, HV power supply is turned off.
440 REM---- - switching deposition dosage accumulation display included on both pages
460 REM---- - Focus control resolution increase, d/a ch. 10; base control, 5000 voltf.s., d/a ch 22; high resolution
control, 800 volt, f.s.
480 REM---- ----- d/a ch. 10 and 22 is connected in series to increase control resolution( normally ch. 10 is set to base
value of 3 KV and remaining part is controlled by ch. 22
500 REM---- ---- multiple layer with different alloy composition entry added.
520 REM---- ---- shut down procedure revised.( operator can stop shut down process
540 REM---- ---- by touching any key while beep is on after deposition dosage
560 REM---- ---- is finished.
580 REM---- ----------------------------------------------------------
600 CLEAR ,,2048
640 OPTION BASE 1
660 DIM ABC$(10)
680 DIM IBEAM(2,3240),IBEXP(2,540) '----ion beam data for every 10 sec, 1 min
```

```
700 DIM IBTEN(2),IBMIN(2) '----ion beam data storage to get 10 sec and 1 min average
720 DIM DAREF(2,24),ADFS(32),DACONT(2,24) '---- reference,full scale, d/a control
740 DIM ADTNEW(2,32),ADTOLD(2,32) '----data table current and old
760 DIM DAFTR(34),DASHFT(24) '----conversion factor for a/d and d/a
780 DIM NFM(16) '----sw table,reference
800 DIM NFTBL(16),NFTOLD(16) '----sw data , current ,old
820 DIM TEMPO(80)
840 DIM XL(10),YL(2,4)
860 DIM CH$(32),CHNAM$(32) '----channel names,for display,for mesaage
880 DIM NFCH$(16),NFM$(16) '----sw channel names
900 DIM NFTBL$(16),AREF$(36),YNEW(3)
920 DIM IBTOTAL(2),SLAYER(2),SLAB(2)
922 DIM TOTALCHARGE(20),DEPCHARGE(20)
940 DIM KYL(10),HI(10),RLOW(10),DOSE(10),YAXIS(10)
942 DIM ACDOSE(10)
944 DIM MAT$(10)
960 MAT$(1)="XX" :MAT$(2)="XX" :START$="XXX"
980 TOTALCHARGE(1)=0 :TOTALCHARGE(2)=0 :IBTOTAL(1)=0 :IBTOTAL(2)=0
1000 DEPCHARGE(1)=0 :DEPCHARGE(2)=0 :SLAYER(1)=0 :SLAYER(2)=0
1020 SLAB(1)=32000 :SLAB(2)=0 :IBTOTAL(1)=0 :IBTOTAL(2)=0 :ACDOSE(1)=0 :ACDOSE(2)=0
1040 KRUN=1 :BCOLOR1=1 :FCOLOR1=15 :BCOLOR2=4 :FCOLOR2=15 :BCOLOR3=0 :FCOLOR3=14
1060 KPCBAD=246 :KTXCTL=247 '----master reference change,pc error
1080 KHENGTM=241 :KLENGTM=242 :KOFFTM=243 '----beam time for high,low enrgy, beam off time
1100 KOFF=0 :INITL=0 :KADCHG=1 :NFCHG=1 :KCONT=249
1120 KFIRST=240 :KSECOND=241 :KLAST=242 '----data packet start and end indicator
1140 IBCNT1=1 :IBCNT2=1 :IBMINCNT1=1 :IBMINCNT2=1 :IBTENCNT1=0 :IBTENCNT2=0 :IBEXPCNT1=1 :IBEXPCNT2=1 :IBMCNT=0 :KSAUTO=0
:ERRNEW=0
1160 WIDTH 80 :SCREEN 0,1,1,1 :COLOR FCOLOR1,BCOLOR1
1180 CLS
1200 DEF SEG=0
1220 FOR I=1 TO 32 :CH$(I)=" " :ADFS(I)=.01 :NEXT
1240 FOR I=1 TO 34 :DAFTR(I)=0 :DASHFT(I)=0 :NEXT
1260 FOR I=11 TO 18 :ADFS(I)=300/256 :DASHFT(I)=2.17 :NEXT '----shim control
1280 DAFTR(1)=.57 :DAFTR(2)=.5150001 :DAFTR(4)=.5142 :DAFTR(6)=.5118 :DAFTR(19)=.9120001 :DAFTR(9)=1.449*.985
1300 DAFTR(3)=.5 :DAFTR(7)=.5
1320 DAFTR(11)=.536*1.015 :DAFTR(12)=.523*.975 :DAFTR(13)=.5135*.9410001 :DAFTR(14)=.531*.9490001
1340 DAFTR(15)=.4922 :DAFTR(16)=.5020001*.9870001 :DAFTR(17)=.5070001 :DAFTR(18)=.51
1360 DAFTR3=.52 :DAFTR(34)=1 '----reference set point store key
1380 DAFTR(20)=.9180001 :DAFTR(21)=.8125 :DAFTR(22)=.50293
1400 DAFTR(34)=1
1420 DASHFT(19)=-19.75 :DASHFT(20)=-20.71 :DASHFT(21)=3.94 :DASHFT(22)=10
1440 FOR I=1 TO 16 :NFCH$(I)=" " :NEXT
```

```
1460 ADFS(1)=1000/256 :ADFS(2)=500/256*.8437 :ADFS(3)=250/256*1.05 :ADFS(4)=20/256*1.09 :ADFS(5)=18/256
1480 ADFS3=2.5/256
1500 ADFS(6)=25/256 :ADFS(7)=15/256 :ADFS(23)=15/256
1520 ADFS(8)=3/256 :ADFS(9)=16/256*1.84 :ADFS(10)=16/256*1.05
1540 ADFS(27)=10/256*1.05527 :ADFS(28)=50/256*1.13
1560 ADFS(29)=5/256 :ADFS(30)=5/256 :ADFS(31)=2.5/256 :ADFS(32)=2.5/256
1580 KEXP30=256/5
1600 ADFS(19)=260/256*1.38 :ADFS(20)=260/256*1.4 :ADFS(21)=500/256*1.06 :ADFS(22)=5/256
1620 RLOW(1)=1000 :RLOW(2)=0 :HI(1)=0 :HI(2)=0 :KOFF=0
1640 DELAV=10 '---- ion source anode voltage minimum control gain range
1660 NBYTE=52
1680 REM---- ------------------------------------------------------------------
1700 REM---- ------ MASTER DISPLAY TABLE NOTE ASSIGN
1720 CHNAM$(1)="ANODE CURRENT " :CHNAM$(2)="ION BEAM ENERGY"
1740 CHNAM$(3)="ION SOURCE ANODE "
1760 CHNAM$(22)="EINZEL LENS FOCUSING" :CHNAM$(4)="ION SOURCE FILAMENT POWER"
1780 CHNAM$(5)="ION SOURCE FILAMENT POWER" :CHNAM$(6)="#1 FURNACE FILAMENT current"
1800 CHNAM$(7)="#2 FURNACE FILAMENT current" :CHNAM$(8)="GAS HANDLING PLANT PRESSURE"
1820 CHNAM$(9)="MAGNET " :CHNAM$(10)="MAGNET"
1840 CHNAM$(11)="SHIM BALANCE" :CHNAM$(12)="SHIM R 1 "
1860 CHNAM$(13)="SHIM R 2 " :CHNAM$(14)="SHIM R 3 "
1880 CHNAM$(15)="SHIM L 1 " :CHNAM$(16)="SHIM L 2 "
1900 CHNAM$(17)="SHIM L 3" :CHNAM$(18)="SHIM MID "
1920 CHNAM$(19)="VELOCITY FILTER " :CHNAM$(20)="VERTICAL DEFLECTION "
1940 CHNAM$(21)="HORIZONTAL DEFLECTION "
1960 CHNAM$(23)="#2 furnace volt " :CHNAM$(24)=" "
1980 CHNAM$(26)=" " :CHNAM$(27)="BEAM ACCEL. ENERGY(KeV)" :CHNAM$(28)="ION BEAM CURRENT"
2000 CHNAM$(29)="TARGET CHAMBER ION GAUGEG "
2020 CHNAM$(30)=" SOURCE CHAMBER ION GAUGE "
2040 CHNAM$(31)=" TARGET CHAMBER FORELINE PRESSURE "
2060 CHNAM$(32)=" SOURCE CHAMBER FORELINE PRESSURE "
2080 CH$(1)="mA anode current" :CH$(2)="eV ion beam energy"
2100 CH$(3)="V anode volt"
2120 CH$(22)="KV focus" :CH$(4)="A source fil." :CH$(5)="V source fil."
2140 CH$(6)="A front furnace " :CH$(7)="A rear furnace " :CH$(8)="mTORR GHP"
2160 CH$(9)="A magnet" :CH$(10)="V magnet" :CH$(11)="V shim balance"
2180 CH$(12)="V shim R 1" :CH$(13)="V shim R 2" :CH$(14)="V shim R 3"
2200 CH$(15)="V shim L 1" :CH$(16)="V shim L 2" :CH$(17)="V shim L 3"
2220 CH$(18)="V shim MID" :CH$(19)="V shim & E-field" :CH$(20)="V vert. defl."
2240 CH$(21)="V horz. defl." :CH$(23)="V rear furnace "
2260 CH$(27)="KeV accel. energy."
2280 CH$(28)="uA ion beam " :CH$(29)="Torr target chamber" :CH$(30)="Torr source chamber" :CH$(31)="mTorr T ch. foreline"
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:CH$(32)="mTorr S ch. foreline"
2300 REM---- -----------------------------------------------------
2320 REM---- -------- A/D D/A CHANNEL MNEUMONIC ASSIGN
2340 ANODI=1 :BEAMV=2 :FOCUSV=3 :SFILI=4 :SFILV=5 :FFILI=6 :FFILV=7 :IGGHP=8
2360 MAGI=9 :MAGV=10 :SHMBAL=11 :SHMR1=12 :SHMR2=13 :SHMR3=14 :SHML1=15 :SHML2=16
2380 SHML3=17 :SHMMID=18 :VELOV=19 :VDEF=20 :HDEF=21
2400 IGFILS=23 :IGFILT=24 '----ion gauge filament sensing
2420 ANODV=25 :BEAMI=28 '----anode voltage and beam current
2440 IGPT=29 :IGPS=30 :IGTFL=31 :IGSFL=32 '----ion gauge pressure, chamber, forelin
2460 REM---- -----------------------------------------------------
2480 REM---- -------- ON/OFF SWITCH CONTROLLER CHANNEL ASSIGN
2500 RPSCH=1 :DPSCH=2 :RPTCH=3 :DPTCH=4 :TURBOP=5 :TURBOH=6 :GATEV=7 :RPGHP=8 :HIVOLT=9 :RACK1=10 :RACK2=11 :RACK3=12
2520 FOR I=1 TO 16 :NFCH$(I)=" " :NEXT
2540 NFCH$(1)="R.P. source ch." :NFCH$(2)="D.P. source ch." :NFCH$(3)="turbo vent valve" :NFCH$(4)="turbo heater "
2560 NFCH$(5)="R.P. target ch." :NFCH$(6)="D.P. target ch." :NFCH$(7)="turbo mol. pump " :NFCH$(8)="turbo gate valve "
2580 NFCH$(9)="R.P. T.CH. roughing" :NFCH$(10)="H.V. cabinet" :NFCH$(16)="high volt" :NFCH$(12)="magnet power supply"
2600 NFCH$(13)="GHP R.P. " :NFCH$(14)="shims & E-field " : NFCH$(15)="horiz. def." :NFCH$(11)="Einzel lens "
2620 TOP=5 :BOTM=20 :LREFCOR=5 :RREFCOR=43 :LDATACOR=12 :RDATACOR=50 :HALF=38
2640 NFTOP=7 :NFBOT=22 :NFREFCOR=35 :NFDATACOR=41
2660 ACFTR=60*ADFS(28)*.000001
2680 REM---- -----------------------------------------------------
2700 REM---- --- dimension declaration,mneumonic and command assignment
2720 FOR I=1 TO 16 :NFM$(I)="off" :NEXT
2740 CLOSE :KEY OFF
2760 OPEN "COM1 :2400,N,8,1,RS,CS,DS,CD" AS #1
2780 OPEN "SCRN :"FOR OUTPUT AS #2
2800 COM(1) ON
2820 REM---- ------ file assignments------------------------
2840 REM------- #1 : serial communication file, #2 : monitor screen
2860 REM------- #3 :C :isdata1, #4 : C :isdata2 -- input/append, ion source control parameter
2880 REM------- #5 :C :ibten1, #6 :C :ibten2 -- append, ion beam current 10 sec data
2900 REM------- #7 :B :setpoint -- input/append ,reference set point storage
2920 REM------- #8 :B :messg -- output, system emergency message storage
2940 REM---- -- open setpoint and message file on drive B
2960 FOR I=1 TO 2 :FOR J=1 TO 32
2980 ADTOLD(I,J)=1 :ADTNEW(I,J)=0 :NEXT :NEXT
3000 FOR I=1 TO 16 :NFTOLD(I)=1 :NFTBL(I)=0 :NFTBL$(I)="OFF" :NEXT
3020 LOCATE 5,5
3040 PRINT " Please enter ion source PID controller parameters." :PRINT "
------------------------------------------------------------ "
3041 LPRINT CHR$(12)
3042 LPRINT " Please enter ion source PID controller parameters." :LPRINT "
```

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-------------------------------------------------------------------- "
3060 PRINT " sampling interval ; T = 0.5 sec "
3062 LPRINT " sampling interval ; T = 0.5 sec "
3080 INPUT " ION SOURCE ANODE VOLTAGE SET POINT ( 60 - 120 ) ",ISAV
3100 PRINT " anode potential reference is ";ISAV;" volt"
3102 LPRINT " anode potential reference is ";ISAV;" volt"
3120 INPUT " CONTROL GAIN (0 - 10) ",SRG :SRCGAN=SRG/1000
3140 PRINT " PID controller gain is ";SRG
3142 LPRINT " PID controller gain is ";SRG
3160 INPUT " INTEGRAL TIME ( x sampling time, 1 - 100 ) ",INTM
3180 PRINT " PID controller integral time is ";INTM*.5;" sec."
3182 LPRINT " PID controller integral time is ";INTM*.5;" sec."
3200 INPUT " DERIVTIVE TIME ( x sampling period, 0.01-1 ) ",DERIVT
3220 PRINT " PID controller derivtive time is ";DERIVT*.5;" sec."
3222 LPRINT " PID controller derivtive time is ";DERIVT*.5;" sec."
3240 PRINT " -----------------------------------------------------------------"
3242 LPRINT " -----------------------------------------------------------------"
3260 PRINT " "
3262 LPRINT " "
3280 SRCINT=1+1/INTM+DERIVT :SRCDRV=1+2*DERIVT
3300 LCNT=1 :LNUM=1 '----number of different composition layers
3320 INPUT " is this dual element deposition ? (Y/N)",DUAL$
3322 LPRINT " is this dual element deposition ? (Y/N)",DUAL$
3340 IF DUAL$="Y"OR DUAL$="y" THEN 3580
3360 IF DUAL$="N" OR DUAL$="n" THEN 3400
3380 PRINT "wrong entry. try again" :GOTO 3320
3400 INPUT " material name ?",MAT$(1)
3402 LPRINT " material name ?",MAT$(1)
3420 PRINT #1,CHR$(KLENGTM);CHR$(1);CHR$(127);
3440 PRINT #1,CHR$(KLENGTM);CHR$(2);CHR$(0);
3460 PRINT #1,CHR$(KOFFTM);CHR$(0);CHR$(0);
3480 PRINT #1,CHR$(KOFFTM);CHR$(0);CHR$(0);
3500 PRINT #1,CHR$(KHENGTM);CHR$(1);CHR$(0);
3520 PRINT #1,CHR$(KHENGTM);CHR$(1);CHR$(0);
3540 INPUT "Enter total deposition dosage of #1 material in Coulomb ",DEPCHARGE(1)
3542 LPRINT "Enter total deposition dosage of #1 material in Coulomb ",DEPCHARGE(1)
3560 GOTO 4100
3580 INPUT "material #1 ?---",MAT$(1)
3582 LPRINT "material #1 ?---",MAT$(1)
3600 INPUT "material #2 ?---",MAT$(2)
3602 LPRINT "material #2 ?---",MAT$(2)
3620 INPUT "number of layers with different composition ? ",LNUM
```

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3622 LPRINT "number of layers with different composition ? ",LNUM
3640 LLNUM=1
3660 JJ=LLNUM*2-1 :KK=JJ+1
3680 PRINT "------ # ";LLNUM; "layer composition program ------- "
3682 LPRINT "------ # ";LLNUM; "layer composition program ------- "
3700 INPUT "high enrgy beam on time #1 in sec. ?-- ",HI(JJ)
3702 LPRINT "high enrgy beam on time #1 in sec. ?-- ",HI(JJ)
3720 INPUT "#1 low enrgy deposition charge in micro Coulomb ?-- ",RLOW(JJ)
3722 LPRINT "#1 low enrgy deposition charge in micro Coulomb ?-- ",RLOW(JJ)
3740 INPUT "#2 high energy beam on time in sec. ?-- ",HI(KK)
3742 LPRINT "#2 high energy beam on time in sec. ?-- ",HI(KK)
3760 INPUT "#2 low energy deposition charge in micro Coulomb ?-- ",RLOW(KK)
3762 LPRINT "#2 low energy deposition charge in micro Coulomb ?-- ",RLOW(KK)
3780 INPUT "Enter total deposition dosage of #1 material in Coulomb ",DEPCHARGE(JJ)
3782 LPRINT "Enter total deposition dosage of #1 material in Coulomb ",DEPCHARGE(JJ)
3800 INPUT "Enter total deposition dosage of #2 material in Coulomb ",DEPCHARGE(KK)
3802 LPRINT "Enter total deposition dosage of #2 material in Coulomb ",DEPCHARGE(KK)
3820 LLNUM=LLNUM+1 :IF LLNUM>>LNUM THEN 3860
3840 GOTO 3660
3860 INPUT "Beam switching time in sec. ?-- ",KOFF
3862 LPRINT "Beam switching time in sec. ?-- ",KOFF
3880 INPUT "beam energy timing schedule ok ? (Y/N)",Y$
3882 LPRINT "beam energy timing schedule ok ? (Y/N)",Y$
3900 IF Y$="Y" OR Y$="y" THEN 3940
3920 CLS :GOTO 3580
3940 SLAB(1)=RLOW(1)*2/ADFS(28) :SLAB(2)=RLOW(2)*2/ADFS(28)
3960 KL1=RLOW(1)*2 :KL2=RLOW(2)*2 :KH1=HI(1)*2 :KH2=HI(2)*2 :KF=KOFF*2
3980 PRINT #1,CHR$(KLENGTM);CHR$(1);CHR$(127);
4000 PRINT #1,CHR$(KLENGTM);CHR$(2);CHR$(O);
4020 PRINT #1,CHR$(KHENGTM);CHR$(1);CHR$(KH1);
4040 PRINT #1,CHR$(KHENGTM);CHR$(2);CHR$(KH2);
4060 PRINT #1,CHR$(KOFFTM);CHR$(KF);CHR$(KF);
4061 LPRINT CHR$(12)
4062 LPRINT " system initialized at ";TIME$,DATE$
4064 LPRINT "**********************************************************"
4066 LPRINT "time, ion, beam, anode, fil(VxA), B/R1/R2/R3/L1/L2/L3/M, focus,low/high, dose"
4068 PRCNT=1000 '----print counter, print every 10 min.(12000 count).
4080 CLS
4100 N=2*LNUM :FOR I=1 TO N
4120 TOTALCHARGE(I)=DEPCHARGE(I)*1000000/(ADFS(28)*60) :NEXT
4140 IVISUAL=O :N=LOC(1) :IF N>>O THEN A$=INPUT$(N,1)
4160 PRINT #1,CHR$(KTXCTL);CHR$(KTXCTL);CHR$(KTXCTL); '----send next data request
```

```
4180 FOR JJJ=1 TO 3 '----6sec delay
4200 GOSUB 15980 :INSEC1=PEEK(&H46C)/18.2+.5
4220 INSEC2=PEEK(&H46C)/18.2+.5 :IF INSEC2=INSEC1 THEN 4220
4240 NEXT
4260 DAREF(1,4)=ADTNEW(1,4) :DAREF(2,4)=DAREF(1,4) :DAREF(1,3)=ADTNEW(1,3) :DAREF(2,3)=DAREF(1,3) :DAREF(1,6)=ADTNEW(1,6)
:DAREF(2,6)=DAREF(1,6)
4280 FOR I=1 TO 16 :NFM(I)=NFTBL(I) :NEXT
4300 FOR JJJ=1 TO 3 '----6 sec delay
4320 GOSUB 15980 :INSEC1=PEEK(&H46C)/18.2+.5
4340 INSEC2=PEEK(&H46C)/18.2+.5 :IF INSEC2=INSEC1 THEN 4340
4360 NEXT
4380 DAREF(1,4)=ADTNEW(1,4) :DAREF(2,4)=DAREF(1,4) :DAREF(1,3)=ADTNEW(1,3) :DAREF(2,3)=DAREF(1,3) :DAREF(1,6)=ADTNEW(1,6)
:DAREF(2,6)=DAREF(1,6)
4400 FOR I=1 TO 16 :NFM(I)=NFTBL(I) :NEXT
4420 REM---- ------------------------------------------------------------
4440 REM---- ---- screen page 0 starts here
4460 WIDTH 80
4480 DISPMODE=0 :VE=0 :IACTIVE=0 :SCREEN 0,1,IACTIVE,IVISUAL :COLOR FCOLOR1,BCOLOR1
4500 CLS :LOCATE 1,15,1,7 :PRINT "****** SYSTEM STATUS ";MAT$(1);" ******";
4520 LOCATE 2,60 :PRINT DATE$; :LOCATE 2,71 :PRINT TIME$;
4540 LOCATE 3,2 :PRINT "CH."; :LOCATE 3,5 :PRINT "REF."; :LOCATE 3,12 :PRINT "DATA"; :LOCATE 3,40 :PRINT "CH."; :LOCATE
3,43 :PRINT "REF."; :LOCATE 3,50 :PRINT "DATA";
4560 LOCATE 23,50 :PRINT "PID";SRCGAN;"/";INTM;"/";DERIVT;"/";GANSLP;
4580 LOCATE 25,1 :PRINT "F1-REF. "; :COLOR FCOLOR3,BCOLOR3 :PRINT " F2-RUN F3-TABLE1 "; :COLOR FCOLOR1,BCOLOR1 :PRINT "
F4-TABLE2 F5-PUMPS F6-BEAM F7-AUTOSOURCE";
4600 A$="off" :IF ISCNT>>0 THEN A$="on "
4620 B$="off" :IF IBREC=1 THEN B$="on "
4640 LOCATE 24,1 :PRINT "F8-anode V rec.";A$; :LOCATE 24,20 :PRINT "F9-anode V graph "; :LOCATE 24,40 :PRINT "F10-beam
rec.";B$;
4660 FOR I=1 TO 16 :J=I+TOP-1 :LOCATE J,1 :PRINT I;
4680 LOCATE J,22 :PRINT CH$(I); :NEXT
4700 FOR I=17 TO 32 :J=I+TOP-17 :LOCATE J,39 :PRINT I;
4720 IF I=22 THEN LOCATE J,RDATACOR :COLOR FCOLOR1,BCOLOR2 :PRINT " ";CH$(I); :COLOR FCOLOR1,BCOLOR1 :GOTO 4780
4740 IF I=27 THEN LOCATE J,RDATACOR :COLOR FCOLOR1,BCOLOR2 :PRINT " ";CH$(I); :COLOR FCOLOR1,BCOLOR1 :GOTO 4780
4760 LOCATE J,60 :PRINT CH$(I)
4780 NEXT
4800 COLOR FCOLOR1,BCOLOR2
4820 FOR I=1 TO 16 :J=I+TOP-1 :LOCATE J,LREFCOR :RDATA=DAREF(1,I)*ADFS(I)
4840 IF I=3 THEN RDATA=ISAV
4860 IF I<>>4 THEN 4900
4880 RDATA=DAREF(1,4)*ADFS(4)+SF3
4900 PRINT USING "###.##";RDATA; :NEXT
```

```
4920 LOCATE J+1,LREFCOR :PRINT USING "######";RLOW(1); :LOCATE J+3,LREFCOR :PRINT KOFF;
4940 LOCATE J+2,LREFCOR :PRINT HI(1);
4960 FOR I=17 TO 24 :J=TOP+I-17 :LOCATE J,RREFCOR :RDATA=DAREF(1,I)*ADFS(I) :PRINT USING "###.##";RDATA;
4980 NEXT
5000 COLOR FCOLOR3,BCOLOR3
5020 FOR I=1 TO 16 :J=I+TOP-1 :LOCATE J,LDATACOR :RDATA=ADTNEW(1,I)*ADFS(I)
5040 PRINT USING "###.##";RDATA; :NEXT
5060 LOCATE J+1,2 :PRINT "**"; :LOCATE J+1,12 :PRINT "uC LOW ENERGY BEAM DEP. DOSAGE "; :LOCATE J+1,65 :PRINT USING
"#.###### C";ACDOSE(1) :LOCATE J+3,2 :PRINT "**"; :LOCATE J+3,12 :PRINT "sec BEAM OFF TIME "
5080 FOR I=17 TO 32 :J=TOP+I-17
5100 LOCATE J,RDATACOR :RDATA=ADTNEW(1,I)*ADFS(I)
5120 IF I=30 THEN KDATAM=INT(RDATA) :REXP=KDATAM-8 :DATAM=RDATA-KDATAM :DATAM=10 DATAM :KDATAM=CINT(DATAM) :PRINT KDATAM;"
X ";REXP; :GOTO 5360
5140 IF I=29 THEN KDATAM=INT(RDATA) :REXP=KDATAM-9 :DATAM=RDATA-KDATAM :DATAM=10 DATAM :KDATAM=CINT(DATAM) :PRINT KDATAM;"
X ";REXP; :GOTO 5360
5160 IF I<31 THEN 5220
5180 RDATA=10 (2.5-RDATA)*5 :IF RDATA>>10000 THEN RDATA=0
5200 GOTO 5280
5220 IF I<>>8 THEN 5280
5240 IF RDATA<.55 THEN RDATA=10 (RDATA*1.7067)*10 :GOTO 5280
5260 RDATA=10 (RDATA*1.09)*20
5280 PRINT USING "###.##";RDATA;
5300 IF I<>>27 THEN 5360
5320 LOCATE 3,63 :COLOR FCOLOR1,BCOLOR2 :IF RDATA>>.1 THEN PRINT " HIGH VOLT ON "; :COLOR FCOLOR3,BCOLOR3 :GOTO 5360
5340 COLOR FCOLOR3,BCOLOR3 :PRINT " HIGH VOLT OFF ";
5360 NEXT
5380 LOCATE J+2,RDATACOR :PRINT "store set points";
5400 LOCATE J+2,2 :PRINT "**"; :LOCATE J+2,12 :PRINT "sec HIGH ENERGY BEAM ON TIME ";
5420 REM---- ----------------------------------------------------------
5440 REM---- ------- screen page 1(material #2) starts to build here
5460 IF DUAL$="n" OR DUAL$="N" THEN 6460
5480 IACTIVE=1 :SCREEN 0,1,IACTIVE,IVISUAL :COLOR FCOLOR2,BCOLOR2
5500 CLS :LOCATE 1,15 :PRINT "****** SYSTEM STATUS "; MAT$(2);" ******"
5520 LOCATE 2,60 :PRINT DATE$; :LOCATE 2,71 :PRINT TIME$;
5540 LOCATE 3,2 :PRINT "CH."; :LOCATE 3,5 :PRINT "REF."; :LOCATE 3,12 :PRINT "DATA"; :LOCATE 3,40 :PRINT "CH."; :LOCATE
3,43 :PRINT "REF."; :LOCATE 3,50 :PRINT "DATA";
5560 LOCATE 23,50 :PRINT "PID";SRCGAN;"/";INTM;"/";DERIVT;"/";GANSLP;
5580 LOCATE 25,1 :PRINT "F1-REF. "; :COLOR FCOLOR3,BCOLOR3 :PRINT " F2-RUN "; :COLOR FCOLOR1,BCOLOR1 :PRINT " F3-TABLE1 ";
:COLOR FCOLOR3,BCOLOR3 :PRINT " F4-TABLE2 "; :COLOR FCOLOR1,BCOLOR1 :PRINT " F5-PUMPS F6-BEAM F7-AUTOSOURCE";
5600 A$="off" :IF ISCNT>>0 THEN A$="on "
5620 B$="off" :IF IBREC=1 THEN B$="on "
5640 LOCATE 24,1 :PRINT "F8-anode V rec.";A$; :LOCATE 24,20 :PRINT "F9-anode V graph "; :LOCATE 24,40 :PRINT "F10-beam
```

```
rec.";B$;
5660 FOR I=1 TO 16 :J=TOP+I-1 :LOCATE J,1 :PRINT I;
5680 LOCATE J,23 :PRINT CH$(I); :NEXT
5700 FOR I=17 TO 32 :J=TOP+I-17 :LOCATE J,39 :PRINT I;
5720 IF I=22 THEN LOCATE J,RDATACOR :COLOR FCOLOR1,BCOLOR2 :PRINT " ";CH$(I); :COLOR FCOLOR2,BCOLOR2 :GOTO 5780
5740 IF I=27 THEN LOCATE J,RDATACOR :COLOR FCOLOR1,BCOLOR2 :PRINT " ";CH$(I); :COLOR FCOLOR2,BCOLOR2 :GOTO 5780
5760 LOCATE J,60 :PRINT CH$(I)
5780 NEXT
5800 COLOR FCOLOR1,BCOLOR1
5820 FOR I=1 TO 16 :J=TOP+I-1 :LOCATE J,LREFCOR :RDATA=DAREF(2,I)*ADFS(I)
5840 IF I=3 THEN RDATA=ISAV
5860 IF I<>4 THEN 5900
5880 RDATA=DAREF(2,4)*ADFS(4)+SF3
5900 PRINT USING "###.##";RDATA; :NEXT
5920 LOCATE J+1,LREFCOR :PRINT USING "######";RLOW(2); :LOCATE J+3,LREFCOR :PRINT KOFF;
5940 LOCATE J+2,LREFCOR :PRINT HI(2);
5960 FOR I=17 TO 24 :J=TOP+I-17 :LOCATE J,RREFCOR :RDATA=DAREF(2,I)*ADFS(I) :PRINT USING "###.##";RDATA; :NEXT
5980 COLOR FCOLOR3,BCOLOR3
6000 FOR I=1 TO 16 :J=TOP+I-1
6020 LOCATE J,LDATACOR :RDATA=ADTNEW(2,I)*ADFS(I)
6040 PRINT USING "###.##";RDATA; :NEXT
6060 LOCATE J+1,2 :PRINT "**"; :LOCATE J+1,12 :PRINT "uC LOW ENERGY BEAM DEP. DOSAGE "; :LOCATE J+1,65 :PRINT USING
"#.###### C";ACDOSE(2) :LOCATE J+3,2 :PRINT "**"; :LOCATE J+3,12 :PRINT "sec BEAM OFF TIME "
6080 FOR I=17 TO 32 :J=TOP+I-17
6100 LOCATE J,RDATACOR :RDATA=ADTNEW(2,I)*ADFS(I)
6120 IF I=30 THEN KDATAM=INT(RDATA) :REXP=KDATAM-8 :DATAM=RDATA-KDATAM :DATAM=10 DATAM :KDATAM=CINT(DATAM) :PRINT KDATAM;"
X ";REXP; :GOTO 6360
6140 IF I=29 THEN KDATAM=INT(RDATA) :REXP=KDATAM-9 :DATAM=RDATA-KDATAM :DATAM=10 DATAM :KDATAM=CINT(DATAM) :PRINT KDATAM;"
X ";REXP; :GOTO 6360
6160 IF I<31 THEN 6220
6180 RDATA=10 (2.5-RDATA)*5 :IF RDATA>>10000 THEN RDATA=0
6200 GOTO 6280
6220 IF I<>>8 THEN 6280
6240 IF RDATA<.55 THEN RDATA=10 (RDATA*1.7067)*10 :GOTO 6280
6260 RDATA=10 (RDATA*1.09)*20
6280 PRINT USING "###.##";RDATA;
6300 IF I<>>27 THEN 6360
6320 LOCATE 3,63 :COLOR FCOLOR1,BCOLOR2 :IF RDATA>>.1 THEN PRINT " HIGH VOLT ON "; :COLOR FCOLOR3,BCOLOR3 :GOTO 6360
6340 COLOR FCOLOR3,BCOLOR3 :PRINT " HIGH VOLT OFF ";
6360 NEXT
6380 LOCATE J+2,RDATACOR :PRINT "store set points";
6400 LOCATE J+2,2 :PRINT "**"; :LOCATE J+2,12 :PRINT "sec HIGH ENERGY BEAM ON TIME ";
```

```
6420 REM---- -------------------------------------------------------
6440 REM---- --------- screen page 2 starts here( pumps status page )
6460 IACTIVE=2 :IVISUAL=2 : :SCREEN 0,1,IACTIVE,IVISUAL :COLOR FCOLOR1,BCOLOR1
6480 CLS :LOCATE 3,15 :PRINT "******* PUMPS STATUS ********";
6500 LOCATE 2,60 :PRINT DATE$; :LOCATE 2,71 :PRINT TIME$;
6520 LOCATE 5,1 :PRINT "CH." :LOCATE 5,12 :PRINT " POWER SOURCE" :LOCATE 5,35 :PRINT "SET" :LOCATE 5,40 :PRINT "STATUS"
6540 FOR I=1 TO 16 :J=NFTOP-1+I :LOCATE J,1 :PRINT I; :LOCATE J,6 :PRINT NFCH$(I); :NEXT
6560 COLOR FCOLOR1,BCOLOR2
6580 FOR I=1 TO 16 :J=NFTOP-1+I :LOCATE J,NFREFCOR
6600 IF I<>3 THEN 6660
6620 IF NFM(I)=1 THEN PRINT "CLOSE "; :GOTO 6760
6640 PRINT "OPEN "; :GOTO 6760
6660 IF I<>8 THEN 6720
6680 IF NFM(I)=1 THEN PRINT "OPEN "; :GOTO 6760
6700 PRINT "CLOSE "; :GOTO 6760
6720 IF NFM(I)=1 THEN PRINT "ON";
6740 IF NFM(I)=0 THEN PRINT "OFF";
6760 NEXT
6780 COLOR FCOLOR3,BCOLOR3
6800 FOR I=1 TO 16 :J=NFTOP-1+I :LOCATE J,NFDATACOR
6820 IF I<>3 THEN 6900
6840 IF NFTBL(I)=1 THEN PRINT "CLOSED"; :GOTO 7040
6860 IF NFTBL(I)=0 THEN PRINT "OPEN "; :GOTO 7040
6880 PRINT "ERROR"; :GOTO 7040
6900 IF I<>8 THEN 6980
6920 IF NFTBL(I)=1 THEN PRINT "OPEN "; :GOTO 7040
6940 IF NFTBL(I)=0 THEN PRINT "CLOSED"; :GOTO 7040
6960 PRINT "ERROR"; :GOTO 7040
6980 IF NFTBL(I)=1 THEN PRINT "ON"; :GOTO 7040
7000 IF NFTBL(I)=0 THEN PRINT "OFF"; :GOTO 7040
7020 IF NFTBL(I)=255 THEN PRINT "ERROR";
7040 NEXT
7060 LOCATE J+1,6 :PRINT "emergency shut down ";
7080 KS$="no " :IF KSHUT=1 THEN KS$="yes"
7100 LOCATE J+1,NFREFCOR :PRINT KS$;
7120 LOCATE J+1,NFDATACOR :PRINT KS$;
7140 COLOR FCOLOR1,BCOLOR1
7160 LOCATE 25,1 :PRINT "F1-STOP "; :COLOR FCOLOR3,BCOLOR3 :PRINT " F2-RUN "; :COLOR FCOLOR1,BCOLOR1 :PRINT " F3-TABLE1
F4-TABLE2 F5-PUMPS F6-BEAM ON/OFF - RETURN KEY ";
7180 LOCATE 5,50 :PRINT "beam started at "; :LOCATE 5,70 :PRINT START$
7200 LOCATE 7,50 :PRINT "MATERIAL #1"; :LOCATE 7,70 :PRINT MAT$(1); :IF MAT$(2)="XX" THEN 7240
7220 LOCATE 8,50 :PRINT "MATERIAL #2"; :LOCATE 8,70 :PRINT MAT$(2);
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7240 LOCATE 10,50 :PRINT MAT$(1);" MAX. DOSE"; :LOCATE 10,70 :PRINT USING "#.#### C";DEPCHARGE(1); :IF MAT$(2)="XX" THEN
7280
7260 LOCATE 11,50 :PRINT MAT$(2);" MAX. DOSE "; :LOCATE 11,70 :PRINT USING "#.#### C";DEPCHARGE(2);
7280 LOCATE 13,50 :PRINT MAT$(1);" ACCUM. DOSE" ;
7300 LOCATE 13,70 :PRINT USING "#.###### ";ACDOSE(1); :PRINT "C"; :IF MAT$(2)="XX" THEN 7360
7320 LOCATE 14,50 :PRINT MAT$(2);" ACCUM. DOSE";
7340 LOCATE 14,70 :PRINT USING "#.###### ";ACDOSE(2); :PRINT "C";
7360 LOCATE 16,50 :PRINT MAT$(1);" BEAM CURRENT ";
7380 BDATA=ADTNEW(1,BEAMI)*ADFS(BEAMI) :X=CINT(BDATA*100)*.01
7400 LOCATE 16,70 :PRINT USING "##.## ";X; :PRINT "uA"; :IF MAT$(2)="XX" THEN 7480
7420 LOCATE 17,50 :PRINT MAT$(2);" BEAM CURRENT ";
7440 BDATA=ADTNEW(2,BEAMI)*ADFS(BEAMI) :X=CINT(BDATA*100)*.01
7460 LOCATE 17,70 :PRINT USING "##.## ";X; :PRINT "uA";
7480 REM---- ----------------------------------------------------------
7500 KEY(1) ON :KEY(2) ON :KEY(3) ON :KEY(4) ON :KEY(5) ON :KEY(6) ON :KEY(7) ON
7520 KEY(8) ON :KEY(9) ON :KEY(10) ON
7540 ON KEY(1) GOSUB 7840 '----stop key, enter new references
7560 ON KEY(2) GOSUB 13140 '----run key, reference entry is over,start data acqusition
7580 ON KEY(3) GOSUB 13400 '----table 1 display, material #1
7600 ON KEY(4) GOSUB 13520 '----table 2 display, material #2
7620 ON KEY(5) GOSUB 13680 '----table 3 display, pump status
7640 ON KEY(6) GOSUB 13820 '----ion beam current vs. time display
7660 ON KEY(7) GOSUB 23180
7680 ON KEY(8) GOSUB 23360
7700 ON KEY(9) GOSUB 23540
7720 ON KEY(10) GOSUB 24340
7740 IFLG9=0 :IFLG10=0
7760 BEEP :INITL=1
7780 IACTIVE=0 :IVISUAL=0 :SCREEN 0,1,IACTIVE,IVISUAL
7800 GOTO 19520
7820 REM---- ----------------------------------------------------------
7840 REM---- --- subroutine F1-REF. routine , reference setting routine
7860 IACTIVE=IVISUAL :KEY(1) OFF
7880 KEY(6) OFF
7900 SCREEN ,,0,IVISUAL
7920 LOCATE 25,1 :COLOR FCOLOR3,BCOLOR3 :PRINT "F1-REF. "; :COLOR FCOLOR1,BCOLOR1 :PRINT " F2-RUN ";
7940 SCREEN ,,1,IVISUAL
7960 LOCATE 25,1 :COLOR FCOLOR3,BCOLOR3 :PRINT "F1-REF. "; :COLOR FCOLOR1,BCOLOR1 :PRINT " F2-RUN ";
7980 SCREEN ,,2,IVISUAL
8000 LOCATE 25,1 :COLOR FCOLOR3,BCOLOR3 :PRINT "F1-REF. "; :COLOR FCOLOR1,BCOLOR1 :PRINT " F2-RUN ";
8020 COLOR FCOLOR1,BCOLOR1 :SCREEN ,,IACTIVE,IVISUAL
8040 POKE &H6A,0 '----flush key buffer
```

```
8060 REM---- ---- cursor control key on
8080 KEY(11) ON :KEY(12) ON : KEY(13) ON :KEY(14) ON
8100 ON KEY(11) GOSUB 12320
8120 ON KEY(12) GOSUB 12620
8140 ON KEY(13) GOSUB 12620
8160 ON KEY(14) GOSUB 12880
8180 KEY(2) ON :KEY(3) ON :KEY(4) ON :KEY(5) ON
8200 LOCATE TOP,LREFCOR
8220 KRUN=0
8240 REM---- -------------------------------------------------------
8260 REM---- --------- monitor a/d master table key entry -----
8280 LOCATE TOP,LREFCOR
8300 INX=1
8320 IVISOLD=IVISUAL
8340 IF KRUN=1 THEN 12260 '----if run key is hit finish this routine
8360 IF IVISUAL=2 THEN 11340 '----if pump status wanted move to page 2
8380 IF IVISUAL<>>IVISOLD THEN 8280 '----if display page changed start again
8400 I=0
8420 IV=IVISUAL+1 :CONTPAGE=IV
8440 NEXTHALF=0 :CSRROW=CSRLIN :CSRCOL=POS(0)
8460 IF CSRCOL>>40 THEN NEXTHALF=16
8480 CHN=CSRROW-4+NEXTHALF :CONTCHN=CHN :CHNUM=CHN+24*IVISUAL :IF CHN>>34 THEN 8280 '----convert row into channel number
8500 UPFLAG=0 :DOWNFLAG=0
8520 AREF$(INX)=INKEY$ :IF AREF$(INX)<>>"" THEN 8660
8540 IF IVISUAL<>>IVISOLD THEN 8280
8560 I=I+1 :IF I<50 THEN 8520 '----key entry monitor loop
8580 KEY(2) STOP :KEY(6) STOP :KEY(11) STOP :KEY(12) STOP :KEY(13) STOP :KEY(14) STOP '----time and buffer monitoring
8600 GOSUB 15940 :KEY(2) ON :KEY(11) ON :KEY(12) ON :KEY(13) ON :KEY(14) ON '----time and buffer monitoring
8620 COLOR FCOLOR1,BCOLOR2
8640 GOTO 8340 '----time and buffer monitoring
8660 NA=ASC(AREF$(INX))
8680 IF NA=13 THEN 9780 '----is it return key ?
8700 IF NA>>57 THEN 8340 '----non numeric keys
8720 IF NA=46 THEN 9700 '----decimal point entered
8740 IF NA>>47 THEN 9700 '----numeric key entered
8760 REM---- ---- up/down control routine (key + or key - )
8780 CONTROW=CSRLIN :CONTCOL=POS(0) :NEXTHALF=0 :IF CONTCOL>>40 THEN NEXTHALF=16
8800 CONTCHN=CONTROW-4+NEXTHALF
8820 IF CONTCHN<>>4 THEN 9220 '----s-fil control, ch4 and ch3
8840 CONTOLD=DAREF(1,3)
8860 IF NA<>>43 THEN 8920
8880 UPFLAG=1 :CONTNEW=CONTOLD+2 :DAREF(1,3)=CONTNEW :DAREF(2,3)=DAREF(1,3) :IF CONTNEW<255 THEN 9080 '----control upwards
```

```
8900 DAREF(1,4)=DAREF(1,4)+32 :DAREF(2,4)=DAREF(1,4) :DAREF(1,3)=0 :DAREF(2,3)=DAREF(1,3) :CONTNEW=0 :GOTO 8980
8920 IF NA<>>45 THEN 8340
8940 DOWNFLAG=1 :CONTNEW=CONTOLD-2 :DAREF(1,3)=CONTNEW :DAREF(2,3)=DAREF(1,3) :IF CONTNEW>>0 THEN 9080 '----control
downwards
8960 DAREF(1,4)=DAREF(1,4)-32 :DAREF(2,4)=DAREF(1,4) :DAREF(1,3)=255 :DAREF(2,3)=DAREF(1,3) :CONTNEW=255 :GOTO 8980
8980 NCONT4=DAREF(1,4)*DAFTR(4)+DASHFT(4)
9000 IF NCONT4>>127 THEN NCONT4=127
9020 IF NCONT4<0 THEN NCONT4=0
9040 PRINT #1,CHR$(KCONT);CHR$(3);CHR$(NCONT4); '----ch4, base change
9060 PRINT #1,CHR$(KCONT);CHR$(27);CHR$(NCONT4); '----ch4, base change
9080 NCONT3=CONTNEW*DAFTR3 :PRINT #1,CHR$(KCONT);CHR$(2);CHR$(NCONT3); '----ch3, high resolution change
9100 PRINT #1,CHR$(KCONT);CHR$(26);CHR$(NCONT3); :BEEP '----ch3, high resolution ch
9120 DISPNEW=DAREF(1,4)*ADFS(4)+DAREF(1,3)*ADFS3
9140 SCREEN ,,0,IVISUAL :LOCATE CONTROW,CONTCOL :PRINT USING "###.###";DISPNEW;
9160 SCREEN ,,1,IVISUAL :LOCATE CONTROW,CONTCOL :PRINT USING "###.###";DISPNEW;
9180 SCREEN ,,IACTIVE,IVISUAL
9200 CONTCNT=4 :GOTO 19520 '----set screen updating count 2 and goto main routine
9220 CONTOLD=DAREF(CONTPAGE,CONTCHN)
9240 IF NA=43 THEN UPFLAG=1 :CONTNEW=CONTOLD+2 :GOTO 9300 '----control upwards
9260 IF NA=45 THEN DOWNFLAG=1 :CONTNEW=CONTOLD-2 :GOTO 9300 '----control downwards
9280 GOTO 8340 '----non numeric keys
9300 DAREF(CONTPAGE,CONTCHN)=CONTNEW
9320 DISPNEW=CONTNEW*ADFS(CONTCHN)
9340 IF CONTCHN=1 THEN 9500
9360 IF CONTCHN=6 THEN 9500
9380 IF CONTCHN=7 THEN 9500
9400 IF CONTCHN=19 THEN 9500
9420 IF CONTCHN=20 THEN 9500
9440 IF CONTCHN=21 THEN 9500
9460 IF CONTCHN=22 THEN DISPNEW=DISPNEW*.16+3
9480 LOCATE CONTROW,CONTCOL :PRINT USING "###.###";DISPNEW; :GOTO 9560
9500 SCREEN ,,0,IVISUAL :LOCATE CONTROW,CONTCOL :PRINT USING "###.###";DISPNEW;
9520 SCREEN ,,1,IVISUAL :LOCATE CONTROW,CONTCOL :PRINT USING "###.###";DISPNEW;
9540 SCREEN ,,IACTIVE,IVISUAL
9560 IDACON=CONTNEW*DAFTR(CONTCHN)+DASHFT(CONTCHN)
9580 IF CONTCHN=22 THEN IDACON=IDACON-DASHFT(22)
9600 IF IDACON>>127 THEN IDACON=127
9620 IF IDACON<1 THEN IDACON=0
9640 CONTCHN=CONTCHN+24*IVISUAL
9660 PRINT #1,CHR$(KCONT);CHR$(CONTCHN-1);CHR$(IDACON); :BEEP
9680 CONTCNT=1 :GOTO 19520 '----set screen updating count 2 and goto main routine
9700 IF INX>>1 THEN 9740 '----now this is legal entry
```

```
9720 PRINT " "; :LOCATE CSRROW,CSRCOL '----wipe old set before writing new
9740 PRINT AREF$(INX); '----write new reference
9760 INX=INX+1 :GOTO 8340
9780 IF CHN<>>34 THEN 9840 '---- if ch34 is on, store reference set points
9800 IF IVISUAL=O THEN GOSUB 26100 :GOTO 11080
9820 IF IVISUAL=1 THEN GOSUB 26280 :GOTO 11080
9840 IF INX=1 THEN 11080
9860 B$="" :FOR I=1 TO INX-1 :B$=B$+AREF$(I) :NEXT '----get all entries
9880 CCOL=LREFCOR :IF NEXTHALF>>O THEN CCOL=RREFCOR
9900 LOCATE CSRROW,CCOL :PRINT " "; :LOCATE CSRROW,CCOL
9920 DATAIN=VAL(B$) '----convert it into decimal
9940 IF CHN=1 THEN 10100
9960 IF CHN=4 THEN 10100
9980 IF CHN=6 THEN 10100
10000 IF CHN=7 THEN 10100
10020 IF CHN=19 THEN 10100
10040 IF CHN=20 THEN 10100
10060 IF CHN=21 THEN 10100
10070 IF NEXTHALF>>O THEN 10080
10072 IF CHN>>16 THEN PRINT USING "######";DATAIN; :GOTO 11160 '----timing set up
10080 GOTO 10160
10100 SCREEN ,,O,IVISUAL :LOCATE CSRROW,CCOL :PRINT USING "###.###";DATAIN;
10120 SCREEN ,,1,IVISUAL :LOCATE CSRROW,CCOL :PRINT USING "###.###";DATAIN;
10140 SCREEN ,,IACTIVE,IVISUAL :GOTO 10180
10160 PRINT USING "###.###";DATAIN;
10180 IF NEXTHALF>>O THEN 10240
10220 IF CHN=3 THEN ISAV=DATAIN :GOTO 11060
10240 IDAR=DATAIN/ADFS(CHN) '----d/a reference
10260 IF IDAR>>255 THEN LOCATE CSRROW,CSRCOL :PRINT " "; :LOCATE CSRROW,CSRCOL :GOTO 8300
10280 IF IDAR=O THEN IDACON=O :GOTO 10920
10300 IDACON=IDAR*DAFTR(CHN)+DASHFT(CHN)
10320 IF IDACON>>127 THEN LOCATE CSRROW,CSRCOL :PRINT " "; :LOCATE CSRROW,CSRCOL :GOTO 8300
10340 IF IDACON<O THEN IDACON=O
10360 IF CHN<>>4 THEN 10660 '----if not source filament control, skip
10380 REM---- ------ source filament entry(ch4 ; base set,multiple of 2.5 amp,ch3; full scale 2.5 amp)
10400 KF4=INT(DATAIN/2.5) :IDAR4=KF4*2.5/ADFS(4) :IDCON4=IDAR4*DAFTR(4)+DASHFT(4)
10420 IF IDAR4=DAREF(IV,4) THEN 10480
10440 PRINT #1,CHR$(KCONT);CHR$(3);CHR$(IDCON4); '----send out control value
10460 BEEP :DAREF(1,4)=IDAR4 :DAREF(2,4)=IDAR4 :DACONT(1,4)=IDCON4 :DACONT(2,4)=IDCON4
10480 SF3=DATAIN-KF4*2.5 :IDAR3=SF3/ADFS3 :IDCON3=IDAR3*DAFTR3+DASHFT(3)
10500 IF IDAR3=DAREF(IV,3) THEN 11080
10520 PRINT #1,CHR$(KCONT);CHR$(2);CHR$(IDCON3); '----send out control value
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```
10540 PRINT #1,CHR$(KCONT);CHR$(26);CHR$(IDCON3); '----send out control value
10560 BEEP :DAREF(1,3)=IDAR3 :DAREF(2,3)=IDAR3 :DACONT(1,3)=IDCON3 :DACONT(2,3)=IDCON3 :GOTO 11080
10580 REM---- ------ source filament entry over
10660 IF CHN<19 THEN 10920
10680 IF CHN<>>22 THEN 10980 '---- if not focusing, skip here
10700 IF DATAIN>>3 THEN 10800
10720 DAREF(IV,10)=DATAIN/ADFS(22) :IDAR10=DAREF(IV,10)*DAFTR(22)+DASHFT(22) :IDAR22=0
10740 KCHN=(IV-1)*24+9 :PRINT #1,CHR$(KCONT);CHR$(KCHN);CHR$(IDAR10);
10760 IF DAREF(IV,22)>>0 THEN DAREF(IV,22)=0 :KCHN=(IV-1)*24+21 :PRINT #1,CHR$(KCONT);CHR$(KCHN);CHR$(0);
10780 GOTO 11060
10800 IDAR10=3/ADFS(22) :D22=(DATAIN-3)/.16 :ID22=D22/ADFS(22) :IDAR22=ID22*DAFTR(22) :IF IDAR22>>127 THEN IDAR22=127
10820 IF DAREF(IV,10)=IDAR10 THEN 10860
10840 DAREF(IV,10)=IDAR10 :IDAR10=IDAR10*DAFTR(22)+DASHFT(22) :KCHN=(IV-1)*24+9 :PRINT #1,
CHR$(KCONT);CHR$(KCHN);CHR$(IDAR10);
10860 DAREF(IV,22)=IDAR22/DAFTR(22) :KCHN=(IV-1)*24+21
10880 PRINT #1,CHR$(KCONT);CHR$(KCHN);CHR$(IDAR22);
10900 GOTO 11060
10920 DAREF(IV,CHN)=IDAR :DACONT(IV,CHN)=IDACON
10940 PRINT #1,CHR$(KCONT);CHR$(CHNUM-1);CHR$(IDACON); '----send out control value
10960 GOTO 11060
10980 DAREF(1,CHN)=IDAR :DACONT(1,CHN)=IDACON
11000 PRINT #1,CHR$(KCONT);CHR$(CHN-1);CHR$(IDACON);
11020 DAREF(2,CHN)=IDAR :DACONT(2,CHN)=IDACON
11040 PRINT #1,CHR$(KCONT);CHR$(CHN+23);CHR$(IDACON);
11060 BEEP
11080 GOSUB 12880 '----move cursor down
11100 IF KRUN=0 THEN 8300
11120 GOTO 12260
11140 IF DATAIN>>255 THEN LOCATE CSRROW,CSRCOL :PRINT " "; :LOCATE CSRROW,CSRCOL :GOTO 8300
11160 IF CHN=17 THEN SLAB(IV)=DATAIN*2/ADFS(28) :RLOW(IV)=DATAIN :DATAIN=0 :GOTO 11060
11180 IF CHN=18 THEN HI(IV)=DATAIN :KD=DATAIN*2 :PRINT #1,CHR$(KHENGTM);CHR$(IV);CHR$(KD); :GOTO 11060
11200 IVK=0 :IF IV=1 THEN IVK=1
11220 SCREEN ,,IVK,IVISUAL :LOCATE 23,LREFCOR :PRINT DATAIN
11240 SCREEN ,,IACTIVE,IVISUAL
11260 IF CHN=19 THEN KOFF=DATAIN :KD=DATAIN*2 :PRINT #1,CHR$(KOFFTM);CHR$(DATAIN);CHR$(KD); :GOTO 11060
11280 GOTO 11060
11300 REM---- -------------------------------------------------------
11320 REM---- ------------pump control entry here
11340 KEY(12) OFF :KEY(13) OFF '----turn off cursor control
11360 A$=INKEY$ :IF A$="" THEN 11400
11380 GOTO 11360
11400 LOCATE NFTOP,NFREFCOR '----align cursor on the reference section
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11420 IF KRUN=1 THEN 12260 '----if run key on, end this routine
11440 CSRROW=CSRLIN :ICH=CSRROW-NFTOP+1 '---- get channel number from cursor pos.
11460 IF ICH>>17 THEN GOSUB 12900 :GOTO 11440 '----if wrong channel no. move cursor down and try to get channel number
again
11480 IF ICH<1 THEN GOSUB 12900 :GOTO 11440
11500 IF IVISUAL<>>2 THEN 8280 '----if mode changed, goto top
11520 I=1
11540 A$=INKEY$ :IF A$="" THEN 11600
11560 KRTN=ASC(A$)
11580 IF KRTN=13 THEN 11700
11600 I=I+1
11620 IF I<10 THEN 11540
11640 KEY(2) STOP :KEY(6) STOP :GOSUB 15940 :KEY(2) ON :KEY(6) ON '----time and buffer check
11660 COLOR FCOLOR1,BCOLOR2
11680 GOTO 11420
11700 IF ICH<>>17 THEN 11860
11720 REM---- --- emergency shut down flag set up, can be set only when beam is flowing and arc current is more than 100
ma
11740 IF KSHUT=1 THEN KSHUT=0 :KS$="off" :PRINT KS$;" ";KS$; :GOTO 11840
11760 IF ADTNEW(1,28)=0 THEN GOTO 11840
11780 IF KOFF=0 THEN 11800 :IF ADTNEW(2,28)=0 THEN 11840 '----if no beam, no activation
11800 IF ADTNEW(1,1)*ADFS(1)<100 THEN 11840 '---- if no arc. no activation
11820 KSHUT=1 :KS$="on " :PRINT KS$;" ";KS$;
11840 GOSUB 12880 :GOTO 11420 '----move cursor and goto top
11860 IF NFM(ICH)=0 THEN 11900
11880 IF NFM(ICH)=1 THEN 12080
11900 IF ICH<>>3 THEN 11940
11920 PRINT "CLOSE "; :GOTO 11980
11940 IF ICH=8 THEN PRINT "OPEN "; :GOTO 11980
11960 PRINT "ON ";
11980 NFM(ICH)=1
12000 ICH=ICH+47
12020 PRINT #1,CHR$(KCONT);CHR$(ICH);CHR$(1); '----send out on reference
12040 BEEP :GOSUB 12880 '----check clock and buffer
12060 GOTO 11420
12080 IF ICH<>>3 THEN 12120
12100 PRINT "OPEN "; :GOTO 12160
12120 IF ICH=8 THEN PRINT "CLOSE "; :GOTO 12160
12140 PRINT "OFF ";
12160 NFM(ICH)=0
12180 ICH=ICH+47
12200 PRINT #1,CHR$(KCONT);CHR$(ICH);CHR$(0); '----send out off reference
```

```
12220 BEEP :GOSUB 12880 '----check clock and buffer
12240 GOTO 11420
12260 COLOR FCOLOR3,BCOLOR3
12280 KEY(6) ON :RETURN
12300 REM---- --------------------------------------------------------
12320 REM---- --- subroutine cursor upwards
12340 X=CSRLIN-1 :YY=POS(0) :Y=RREFCOR :NEXTHALF=16
12360 IF IVISUAL<2 THEN 12420
12380 IF X<NFTOP THEN X=NFBOT+1
12400 LOCATE X,NFREFCOR :RETURN
12420 IF X<TOP THEN X=BOTM+3
12440 IF X<TOP THEN X=BOTM+3
12460 IF YY>>HALF THEN 12520
12480 IF X=7 THEN X=6
12500 Y=LREFCOR :NEXTHALF=0
12520 CHNUM=X-4+NEXTHALF :IF CHNUM>>35 THEN X=5 :GOTO 12520
12540 LOCATE X,Y
12560 IF DAFTR(CHNUM)=0 THEN 12340
12580 RETURN
12600 REM---- --------------------------------------------------------
12620 REM---- ---- subroutine cursor left and right
12640 IF IVISUAL=2 THEN 12840
12660 X=CSRLIN :YY=POS(0) :Y=RREFCOR
12680 IF X<5 THEN 12660
12700 IF X>>19 THEN 12660
12720 NEXTHALF=16 :IF YY>>HALF THEN Y=LREFCOR :NEXTHALF=0
12740 LOCATE X,Y
12760 CHNUM=X-4+NEXTHALF :IF CHNUM>>35 THEN CHNUM=17 :LOCATE 5,RREFCOR
12780 IF CHNUM>>35 THEN RETURN
12800 IF CHNUM<1 THEN RETURN
12820 IF DAFTR(CHNUM)=0 THEN GOSUB 12900
12840 RETURN
12860 REM---- --------------------------------------------------------
12880 REM---- ---- subroutine cursor downwards
12900 X=CSRLIN+1 :YY=POS(0) :Y=RREFCOR :NEXTHALF=16
12920 IF IVISUAL<2 THEN 12980
12940 IF X>>NFBOT+1 THEN X=NFTOP
12960 LOCATE X,NFREFCOR :RETURN
12980 IF X>>BOTM+3 THEN X=TOP
13000 IF YY>>HALF THEN 13040
13020 Y=LREFCOR :NEXTHALF=0
13040 CHNUM=X-4+NEXTHALF :IF CHNUM>>35 THEN X=5 :GOTO 13040
```

```
13060 LOCATE X,Y
13080 IF DAFTR(CHNUM)=0 THEN 12900
13100 RETURN
13120 REM---- ---------------------------------------------------------
13140 REM---- --- SUBROUTINE F2-RUN routine
13160 KEY(1) ON :KEY(2) OFF :KEY(6) ON :KEY(11) OFF :KEY(12) OFF :KEY(13) OFF :KEY(14) OFF
13180 RROW=CSRLIN :RPOS=POS(0)
13200 SCREEN ,,0,IVISUAL
13220 LOCATE 25,1 :COLOR FCOLOR1,BCOLOR1 :PRINT "F1-REF. "; :COLOR FCOLOR3,BCOLOR3 :PRINT " F2-RUN ";
13240 SCREEN ,,1,IVISUAL
13260 LOCATE 25,1 :COLOR FCOLOR1,BCOLOR1 :PRINT "F1-REF. "; :COLOR FCOLOR3,BCOLOR3 :PRINT " F2-RUN ";
13280 SCREEN ,,2,IVISUAL
13300 LOCATE 25,1 :COLOR FCOLOR1,BCOLOR1 :PRINT "F1-REF. "; :COLOR FCOLOR3,BCOLOR3 :PRINT " F2-RUN ";
13320 KRUN=1 :LOCATE RROW,RPOS :SCREEN ,,IACTIVE,IVISUAL
13340 RETURN
13360 REM---- ---------------------------------------------------------
13380 REM---- --- SUBROUTINE, F3-TABLE1 routine
13400 IVISUAL=0 :IACTIVE=0 :SCREEN 0,1,IACTIVE,IVISUAL
13420 TROW=CSRLIN :TPOS=POS(0) :LOCATE 25,17 :COLOR FCOLOR3,BCOLOR3 :PRINT " F3-TABLE1 "; :COLOR FCOLOR1,BCOLOR1 :PRINT "
F4-TABLE2 F5-PUMPS "; :LOCATE TROW,TPOS
13440 COLOR FCOLOR1,BCOLOR1
13460 KEY(3) OFF :KEY(4) ON :KEY(5) ON
13480 RETURN
13500 REM---- ---------------------------------------------------------
13520 REM---- --- SUBROUTINE, F4-TABLE2 routine
13540 IF DUAL$="n" OR DUAL$="N" THEN 13640
13560 IVISUAL=1 :IACTIVE=1 :SCREEN 0,1,IACTIVE,IVISUAL
13580 TROW=CSRLIN :TPOS=POS(0) :LOCATE 25,17 :COLOR FCOLOR1,BCOLOR1 :PRINT " F3-TABLE1 "; :COLOR FCOLOR3,BCOLOR3 :PRINT "
F4-TABLE2 "; :COLOR FCOLOR1,BCOLOR1 :PRINT " F5-PUMPS "; :LOCATE TROW,TPOS
13600 COLOR FCOLOR2,BCOLOR2
13620 KEY(4) OFF :KEY(3) ON :KEY(5) ON
13640 RETURN
13660 REM---- ---------------------------------------------------------
13680 REM---- --- SUBROUTINE, F5-PUMPS routine
13700 IVISUAL=2 :IACTIVE=2 :SCREEN 0,1,IACTIVE,IVISUAL
13720 TROW=CSRLIN :TPOS=POS(0) :LOCATE 25,17 :COLOR FCOLOR1,BCOLOR1 :PRINT " F3-TABLE1 F4-TABLE2 "; :COLOR FCOLOR3,BCOLOR3
:PRINT " F5-PUMPS "; :LOCATE TROW,TPOS
13740 COLOR FCOLOR1,BCOLOR1
13760 KEY(5) OFF :KEY(3) ON :KEY(4) ON
13780 RETURN
13800 REM---- ---------------------------------------------------------
13820 REM---- --- SUBROUTINE, F6-BEAM routine
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13840 BEAMT=IBMCNT
13860 SCREEN 0,1,2,2 :CLS :SCREEN ,,1,1 :CLS :SCREEN ,,0,0 :CLS :SCREEN 2
13880 LOCATE 25,1 :PRINT "F1-TABLES F10-1.5/9 HOUR L/R - TIME REGION ";
13900 LOCATE 1,10 :PRINT "*** ION BEAM CURRENT VS. TIME ***"; :LOCATE 2,60 :PRINT DATE$; :LOCATE 2,71 :PRINT TIME$;
13920 YSTEP=80 :BAR=3 :LBAR=5 :DOWN=70 :RIGHT=580 :Y1=10 :XO=60 :Y2=90 :KYL(1)=0 :KYL(2)=80
13940 KEY(2) OFF :KEY(3) OFF :KEY(4) OFF :KEY(5) OFF :KEY(6) OFF :KEY(11) OFF :KEY(14) OFF
13960 KEY(9) OFF :KEY(10) OFF
13980 DISPMODE=1 :OLDHR=HREGION :OLDEXP=KEXP
14000 KEY(1) ON :KEY(12) ON :KEY(13) ON :KEY(10) ON
14020 ON KEY(1) GOSUB 23140
14040 ON KEY(12) GOSUB 22940
14060 ON KEY(13) GOSUB 22840
14080 ON KEY(10) GOSUB 23060
14100 PSET(XO,Y1) :DRAW "D="+VARPTR$(DOWN) :DRAW "R="+VARPTR$(RIGHT)
14120 PSET(XO,Y2) :DRAW "D="+VARPTR$(DOWN) :DRAW "R="+VARPTR$(RIGHT)
14140 LOCATE 3,1 :PRINT MAT$(1)
14160 LOCATE 14,1 :PRINT MAT$(2)
14180 LOCATE 2,5 :PRINT "uA";
14200 LOCATE 3,5 :PRINT "30";
14220 LOCATE 5,5 :PRINT "20"
14240 LOCATE 8,5 :PRINT "10";
14260 LOCATE 12,5 :PRINT "uA";
14280 LOCATE 13,5 :PRINT "30";
14300 LOCATE 15,5 :PRINT "20";
14320 LOCATE 17,5 :PRINT "10";
14340 LOCATE 12,76 :PRINT "HOUR";
14360 LOCATE 22,76 :PRINT "HOUR";
14380 KEY(1) STOP :KEY(12) STOP :KEY(13) STOP :KEY(10) STOP
14400 REM---------- start drawing data on x-y axis
14420 IF KEXP=1 THEN 14840
14440 HSTRT=HREGION*540+1 :HEND=HSTRT+540 :YAXIS(1)=80 :YAXIS(2)=160
14460 FOR IDSP=1 TO 2 :ROW=12+(IDSP-1)*10
14480 HR=1.5*HREGION :LOCATE ROW,8 :PRINT HR;" ";
14500 HR=.5+1.5*HREGION :LOCATE ROW,30 :PRINT HR;" ";
14520 HR=HR+.5 :LOCATE ROW,52 :PRINT HR;" ";
14540 Y=YAXIS(IDSP) :XDSP=XO :PSET (XDSP,Y)
14560 REM---- ---- plot value has been calculated and draw starts here
14580 IF IDSP=1 THEN 14640
14600 IF HEND>>IBCNT2 THEN HEND=IBCNT2
14620 GOTO 14660
14640 IF HEND>>IBCNT1 THEN HEND=IBCNT1
14660 FOR HST=HSTRT TO HEND
```

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14680 ILEN=IBEAM(IDSP,HST)*ADFS(28)*2 :YNEW(IDSP)=Y-ILEN
14700 LINE -(XDSP,YNEW(IDSP))
14720 XDSP=XDSP+1
14740 KPL=KPL+1 :IF KPL>>100 THEN KPL=0 :GOSUB 15940
14760 NEXT
14780 NEXT
14800 GOTO 15080
14820 REM---- ---- 9 hour scale draw starts here
14840 FOR I=1 TO 2 :ROW=12+(I-1)*10
14860 LOCATE ROW,8 :PRINT "0.0 ";
14880 LOCATE ROW,30 :PRINT "3.0";
14900 LOCATE ROW,52 :PRINT "6.0";
14920 X=XO :YAXIS(1)=80 :YAXIS(2)=160 :Y=YAXIS(I) :PSET (X,Y)
14940 IF I=2 THEN 14980
14960 MINEND=IBEXPCNT1 :GOTO 15000
14980 MINEND=IBEXPCNT2
15000 FOR HST=1 TO MINEND :ILEN=IBEXP(I,HST)*ADFS(28)*2
15020 YNEW(I)=YAXIS(I)-ILEN :LINE -(X,YNEW(I))
15040 X=X+1 :NEXT
15060 NEXT :IBMOLD1=IBEXPCNT1 :IBMOLD2=IBEXPCNT2
15080 FOR IYL=1 TO 2 :FOR JYL=1 TO 4 :YL(IYL,JYL)=KYL(IYL)+JYL*20 :YPOS=YL(IYL,JYL) :PSET (XO,YPOS)
15100 DRAW "L="+VARPTR$(BAR) :NEXT
15120 FOR IXL=1 TO 9 :XL(IXL)=XO+60*IXL :XPOS=XL(IXL) :YPOS=YL(IYL,4) :PSET(XPOS,YPOS) :DRAW "D="+VARPTR$(BAR) :NEXT :NEXT
15140 KEY(1) ON :KEY(12) ON :KEY(13) ON :KEY(10) ON
15160 IF DISPMODE=2 THEN 15820
15180 IF HREGION<>>OLDHR THEN 13860
15200 IF KEXP<>>OLDEXP THEN 13860
15220 KEY(1) STOP :KEY(12) STOP :KEY(13) STOP :KEY(10) STOP :GOSUB 15940 :KEY(1) ON :KEY(12) ON :KEY(13) ON :KEY(10) ON
15240 REM---- ------------------------------------------------------------
15260 REM---- ------ graphic mode screen updating ------------------------------
15280 IF KEXP=1 THEN 15600
15300 IF IBTENCNT<>>0 THEN 15160
15320 KHR=(HREGION+1)*540 :IF KHR<IBCNT1 THEN 15160
15340 KHR=KHR-540 :IF KHR>>IBCNT1 THEN 15160
15360 MX=XO+IBCNT1-KHR
15380 IF MX>>639 THEN 15160
15400 IF MX<1 THEN 15160
15420 KEY(1) STOP :FOR I=1 TO 2
15440 IF I=1 THEN IBCNT=IBCNT1
15460 IF I=2 THEN IBCNT=IBCNT2
15480 IF YNEW(I)>>198 THEN 15560
15500 PSET (MX-1,YNEW(I))
```

```
15520 ILEN=IBEAM(I,IBCNT)*ADFS(28)*2 :YNEW(I)=YAXIS(I)-ILEN
15540 LINE -(MX,YNEW(I))
15560 NEXT :KEY(1) ON
15580 GOTO 15160
15600 IF IBMOLD1<IBEXPCNT1 THEN 15640
15620 IF IBMOLD2=IBEXPCNT2 THEN 15160
15640 YAXIS(1)=80 :YAXIS(2)=160
15660 KEY(1) STOP :FOR MI=1 TO 2
15680 IF MI=1 THEN IBMINCNT=IBEXPCNT1
15700 IF MI=2 THEN IBMINCNT=IBEXPCNT2
15720 MX=XO+IBMINCNT
15740 MY=YAXIS(MI) :PSET (MX-1,YNEW(I)) :ILEN=IBEXP(MI,IBMINCNT)*ADFS(28)*2
15760 YNEW(I)=YAXIS(I)-ILEN :LINE -(MX,YNEW(I))
15780 NEXT :KEY(1) ON :IBMOLD1=IBEXPCNT1 :IBMOLD2=IBEXPCNT2
15800 GOTO 15160
15820 KEY(10) OFF :KEY(1) OFF :KEY(12) OFF :KEY(13) OFF
15840 BEEP :SCREEN 0,1,0,0
15860 RETURN
15880 REM---- -------------------------------------------------------
15900 REM---- ---- SUBROUTINE time and Rx buffer check, display updating
15920 REM---- -------------------------------------------------------
15940 REM---- ------- RX buffer check ,decoding and store data into array
15960 REM---- ------- RX buffer check ,decoding and store data into array
15980 IF KCOMOK=1 THEN 16100
16000 ON ERROR GOTO 18940
16020 N=LOC(1) :IF N<NBYTE THEN 18940
16040 N1=ASC(INPUT$(1,1)) :IF N1=KFIRST THEN 16080
16060 BEEP :GOTO 16020
16080 N2=ASC(INPUT$(1,1)) :IF N2<>>KSECOND THEN 18940
16100 N=LOC(1) :KCOMOK=0 :IF N<50 THEN KCOMOK=1 :GOTO 18940
16120 NMOD=ASC(INPUT$(1,1)) '----beam mode
16140 FOR IT=1 TO 48 :TEMPO(IT)=ASC(INPUT$(1,1))
16160 NEXT
16180 K=ASC(INPUT$(1,1)) :IF K<>>KLAST THEN BEEP :GOTO 18940
16200 NEWSET=1 :IF KSFLAG=0 THEN 16240
16220 SHUTCNT=SHUTCNT-1 '----reduce time out counter value
16240 IF NMOD=2 THEN 16300 '----beam off
16260 IF NMOD=5 THEN 16300 '----beam off
16280 GOTO 16380
16300 FOR I=1 TO 2 :FOR J=3 TO 7 :IF TEMPO(I)=ADTNEW(I,J) THEN 16340
16320 ADTNEW(I,J)=TEMPO(J) :ADTOLD(I,J)=1 :KADCHG=1
16340 NEXT :NEXT '----if beam off, update fil. data
```

```
16360 GOTO 17340 '----goto ac switch update
16380 KN=1 :IF NMOD>>2 THEN KN=2
16400 IF KRUN=0 THEN 16720
16420 IF DISPMODE>>0 THEN 16720
16440 IF NMOD=0 THEN 16480 '----if #1 material data, print #1 on
16460 IF NMOD<>>1 THEN 16580 '----if #1 material data, print #1 on
16480 RX=CSRLIN :RY=POS(0)
16500 SCREEN 0,1,0,IVISUAL :LOCATE 1,1 :PRINT MAT$(1);" on ";
16520 SCREEN 0,1,1,IVISUAL :LOCATE 1,1 :PRINT MAT$(2);" off";
16540 SCREEN 0,1,2,IVISUAL :LOCATE 1,1 :PRINT MAT$(1);" on ";
16560 SCREEN 0,1,IACT,IVISUAL :LOCATE RX,RY :GOTO 16720
16580 IF NMOD=3 THEN 16620
16600 IF NMOD<>>4 THEN 16720
16620 RX=CSRLIN :RY=POS(0)
16640 SCREEN 0,1,1,IVISUAL :LOCATE 1,1 :PRINT MAT$(2);" on ";
16660 SCREEN 0,1,0,IVISUAL :LOCATE 1,1 :PRINT MAT$(1);" off";
16680 SCREEN 0,1,2,IVISUAL :LOCATE 1,1 :PRINT MAT$(2);" on ";
16700 SCREEN 0,1,IACT,IVISUAL :LOCATE RX,RY
16720 IF TEMPO(2)<>>ADTNEW(KN,2) THEN ADTOLD(KN,2)=1 :ADTNEW(KN,2)=TEMPO(2) :KADCHG=1
16740 FOR IT=3 TO 7
16760 IF TEMPO(IT)<>>ADTNEW(KN,IT) THEN ADTOLD(KN,IT)=1 :ADTNEW(KN,IT)=TEMPO(IT) :KADCHG=1
16780 NEXT
16800 FOR IT=9 TO 18
16820 IF TEMPO(IT)<>>ADTNEW(KN,IT) THEN ADTOLD(KN,IT)=1 :ADTNEW(KN,IT)=TEMPO(IT) :KADCHG=1
16840 NEXT
16860 IF TEMPO(22)<>>ADTNEW(KN,22) THEN ADTOLD(KN,22)=1 :ADTNEW(KN,22)=TEMPO(22) :KADCHG=1
16880 IF TEMPO(28)<>>ADTNEW(KN,28) THEN ADTOLD(KN,28)=1 :ADTNEW(KN,28)=TEMPO(28) :KADCHG=1
16900 JT=1
16920 IF TEMPO(1)<>>ADTNEW(JT,1) THEN ADTOLD(JT,1)=1 :ADTNEW(JT,1)=TEMPO(1) :KADCHG=1
16940 FOR IT=3 TO 8
16960 IF TEMPO(IT)<>>ADTNEW(JT,IT) THEN ADTOLD(JT,IT)=1 :ADTNEW(JT,IT)=TEMPO(IT) :KADCHG=1
16980 NEXT
17000 FOR IT=19 TO 21
17020 IF TEMPO(IT)<>>ADTNEW(JT,IT) THEN ADTOLD(JT,IT)=1 :ADTNEW(JT,IT)=TEMPO(IT) :KADCHG=1
17040 NEXT
17060 FOR IT=23 TO 27
17080 IF TEMPO(IT)<>>ADTNEW(JT,IT) THEN ADTOLD(JT,IT)=1 :ADTNEW(JT,IT)=TEMPO(IT) :KADCHG=1
17100 NEXT
17120 FOR IT=29 TO 32
17140 IF TEMPO(IT)<>>ADTNEW(JT,IT) THEN ADTOLD(JT,IT)=1 :ADTNEW(JT,IT)=TEMPO(IT) :KADCHG=1
17160 NEXT
17180 IF START$<>>"XXX" THEN 17300
```

```
17200 IF ADTNEW(1,27)>>10 THEN 17240
17220 IF ADTNEW(2,27)<10 THEN 17300
17240 START$=TIME$ :IF DISPMODE>>0 THEN 17300
17260 SCREEN 0,1,2,IVISUAL :LOCATE 5,70 :PRINT START$;
17280 SCREEN 0,1,IACT,IVISUAL
17300 IF KOFF=0 THEN 17340
17320 JT=JT+1 :IF JT=2 THEN 16920
17340 FOR IT=1 TO 16
17360 KT=IT+32
17380 IF TEMPO(KT)=NFTBL(IT) THEN 17440
17400 NFTOLD(IT)=1
17420 NFTBL(IT)=TEMPO(KT) :NFCHG=1
17440 NEXT
17460 REM---- -- ion beam data 10 sec. and 1 min. averaging
17480 IF NMOD=0 THEN 17640
17500 IF NMOD=3 THEN 18280
17520 IF NMOD=1 THEN 17580
17540 IF NMOD=4 THEN 17600
17560 GOTO 18940
17580 IF KOFF=0 THEN GOSUB 24640 :GOTO 18940
17600 IF KOFF=0 THEN GOSUB 24520 :GOTO 18940
17620 GOTO 18940
17640 IBTEN(1)=ADTNEW(1,BEAMI)+IBTEN(1)
17660 SLAYER(1)=SLAYER(1)+ADTNEW(1,BEAMI)
17680 IF SLAYER(1)=>>SLAB(1) THEN SLAYER(1)=0 :GOSUB 24520 '----layer total chrge reach the ceiling, then switch next
material deposition
17700 TENCNT1=TENCNT1+1 :IF TENCNT1<20 THEN 18940
17720 TENCNT1=0 :IBTEN(1)=IBTEN(1)/20 :IBCNT1=IBCNT1+1
17740 IBEAM(1,IBCNT1)=IBTEN(1)
17760 IF IBCNT1>>3239 THEN IBCNT1=3239
17780 IBTENTTL1=IBTENTTL1+IBTEN(1)
17800 ACDOSE(1)=IBTENTTL1*ACFTR/6 '----dose calculation every 10 sec.
17820 IF IBREC=0 THEN 17880
17840 BEAM1=IBEAM(1,IBCNT1)*ADFS(28)
17860 PRINT#5,USING "##.##,";BEAM1;
17880 IBMIN(1)=IBMIN(1)+IBTEN(1) :IBTEN(1)=0
17900 MINCNT1=MINCNT1+1 :IF MINCNT1<6 THEN 18940
17920 IBMIN(1)=IBMIN(1)/6 :MINCNT1=0 :IBEXPCNT1=IBEXPCNT1+1
17940 IBEXP(1,IBEXPCNT1)=IBMIN(1)
17960 IBTOTAL(1)=IBTOTAL(1)+IBMIN(1)
17980 IBMIN(1)=0
18000 IF KOFF>>0 THEN 18940
```

```
18020 IF IBTOTAL(1)<TOTALCHARGE(1) THEN 18940
18040 LPRINT TIME$,LCNT;" layer deposition finished " :LCNT=LCNT+1
18060 JJ=2*LCNT-1 :KK=2*LCNT
18080 DEPCHARGE(1)=DEPCHARGE(JJ) :DEPCHARGE(2)=DEPCHARGE(KK)
18100 TOTALCHARGE(1)=TOTALCHARGE(JJ) :TOTALCHARGE(2)=TOTALCHARGE(KK)
18120 HI(1)=HI(JJ) :RLOW(1)=RLOW(JJ) :HI(2)=HI(KK) :RLOW(2)=RLOW(KK)
18140 IBTOTAL(1)=0 :IBTOTAL(2)=0 :TENCNT1=0 :TENCNT2=0 :IBTEN(1)=0 :IBTEN(2)=0
18160 IBTENTTL1=0 :IBTENTTL2=0
18180 IBMIN(1)=0 :IBMIN(2)=0 :MINCNT1=0 :MINCNT2=0
18200 ACDOSE(1)=0 :ACDOSE(2)=0
18220 IF LCNT>>LNUM THEN LPRINT TIME$, "overall deposition finished " :GOSUB 24760
18240 LSW=1
18260 GOTO 18940
18280 IBTEN(2)=ADTNEW(2,BEAMI)+IBTEN(2)
18300 IF KOFF=0 THEN 18360
18320 SLAYER(2)=SLAYER(2)+ADTNEW(2,BEAMI)
18340 IF SLAYER(2)=>>SLAB(2) THEN SLAYER(2)=0 :GOSUB 24620 '----if #2 deposition layer done, switch material
18360 TENCNT2=TENCNT2+1 :IF TENCNT2<20 THEN 18940
18380 TENCNT2=0 :IBTEN(2)=IBTEN(2)/20
18400 IBCNT2=IBCNT2+1
18420 IF IBCNT2>>3239 THEN IBCNT2=3239
18440 IBEAM(2,IBCNT2)=IBTEN(2)
18460 IBTENTTL2=IBTENTTL2+IBTEN(2)
18480 ACDOSE(2)=IBTENTTL2*ACFTR/6 '----dose calculation every 10 sec.
18500 IF IBREC=0 THEN 18560 '----if rec. is not on skip this
18520 BEAM2=IBEAM(2,IBCNT2)*ADFS(28)
18540 PRINT#6,USING "##.##,";BEAM2;
18560 IBMIN(2)=IBMIN(2)+IBTEN(2) :IBTEN(2)=0
18580 MINCNT2=MINCNT2+1 :IF MINCNT2<6 THEN 18940
18600 IBMIN(2)=IBMIN(2)/6 :MINCNT2=0 :IBEXPCNT2=IBEXPCNT2+1
18620 IF IBEXPCNT2>>539 THEN IBEXPCNT2=539
18640 IBEXP(2,IBEXPCNT2)=IBMIN(2)
18660 IBTOTAL(2)=IBTOTAL(2)+IBMIN(2) :IBMIN(2)=0
18680 IF IBTOTAL(2)<TOTALCHARGE(2) THEN 18940
18700 LPRINT TIME$,LCNT;" layer deposition finished " :LCNT=LCNT+1
18720 JJ=2*LCNT-1 :KK=2*LCNT
18740 DEPCHARGE(1)=DEPCHARGE(JJ) :DEPCHARGE(2)=DEPCHARGE(KK)
18760 TOTALCHARGE(1)=TOTALCHARGE(JJ) :TOTALCHARGE(2)=TOTALCHARGE(KK)
18780 HI(1)=HI(JJ) :HI(2)=HI(KK) :RLOW(1)=RLOW(JJ) :RLOW(2)=RLOW(KK)
18800 IBTOTAL(1)=0 :IBTOTAL(2)=0 :TENCNT1=0 :TENCNT2=0 :IBTEN(1)=0 :IBTEN(2)=0
18820 IBTENTTL1=0 :IBTENTTL2=0
18840 IBMIN(1)=0 :IBMIN(2)=0 :MINCNT1=0 :MINCNT2=0
```

```
18860 ACDOSE(1)=0 :ACDOSE(2)=0
18880 IF LCNT>>LNUM THEN GOSUB 24760
18900 IF KFINISH=1 THEN LPRINT TIME$," overall deposition is over"
18920 LSW=1
18940 KO=PEEK(&H46C) :K1=PEEK(&H46D) :K2=PEEK(&H46E) :K3=PEEK(&H46F)
18960 NSEC=INT(KO/9.1+.5) '----every 0.5 sec data request on
18980 IF NSEC=NSECOLD THEN 19440
19000 NEWSET=1 '----new data set arrival flag
19020 OLDROW=CSRLIN :OLDCOL=POS(0) '----keep old position before writing LIST 40470-
19040 NSECOLD=NSEC
19060 IF IFLG9=1 THEN 19400
19080 IF DISPMODE=0 THEN 19160
19100 IF NEWDATE=0 THEN 19140
19120 LOCATE 2,60 :PRINT DATE$; :NEWDATE=0
19140 LOCATE 2,71 :PRINT TIME$; :GOTO 19400
19160 FOR IA=0 TO 2 :SCREEN 0,1,IA,IVISUAL
19180 IF NEWDATE=0 THEN 19220
19200 LOCATE 2,60 :PRINT DATE$; :NEWDATE=0
19220 LOCATE 2,71 :PRINT TIME$;
19240 IF IA<>>2 THEN 19360
19260 B1=ADTNEW(1,28)*ADFS(28) :B2=ADTNEW(2,28)*ADFS(28)
19280 LOCATE 13,70 :PRINT USING "#.###### C";ACDOSE(1);
19300 LOCATE 14,70 :PRINT USING "#.###### C";ACDOSE(2);
19320 LOCATE 16,70 :PRINT USING "##.## uA";B1;
19340 LOCATE 17,70 :PRINT USING "##.## uA";B2;
19360 NEXT
19380 SCREEN 0,1,IACTIVE,IVISUAL
19400 LOCATE OLDROW,OLDCOL '----restore old position
19420 PRINT #1,CHR$(KTXCTL);CHR$(KTXCTL);CHR$(KTXCTL); '----send next data request
19422 PRCNT=PRCNT+1
19424 IF PRCNT>>1200 THEN GOSUB 19442 '----every 10 min. send data to printer
19440 ON ERROR GOTO 0 :RETURN
19441 REM---- ---- data printing subroutine
19442 PRCNT=0 :J=1
19444 TI$=LEFT$(TIME$,5) :LPRINT TI$; :LPRINT " ";MAT$(J);
19446 BEAM=ADTNEW(J,28)*ADFS(28) :LPRINT USING "##.#uA";BEAM;
19448 ANOD=ADTNEW(J,3)*ADFS(3) :LPRINT USING "###V";ANOD;
19450 SFI=ADTNEW(J,4)*ADFS(4) :SFV=ADTNEW(J,5)*ADFS(5)
19452 LPRINT USING "###A";SFI; :LPRINT USING "##V";SFV;
19454 FOR I=11 TO 17 :SHIM=ADTNEW(J,I)*ADFS(I)
19456 LPRINT USING "###/";SHIM; :NEXT
19457 SHIM=ADTNEW(J,18)*ADFS(18)
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```
19458 LPRINT USING "###";SHIM;
19459 FO=ADTNEW(J,22)*ADFS(22) :LPRINT USING "##.#KV";FO;
19460 LPRINT USING "#####uC";RLOW(J);
19462 LPRINT USING "###sec";HI(J);
19464 LPRINT USING "##.###C";ACDOSE(J)
19466 IF J>>1 THEN 19470
19468 IF DUAL$="Y" THEN J=2 :GOTO 19444
19469 IF DUAL$="y" THEN J=2 :GOTO 19444
19470 RETURN
19478 REM---- ----------------------------------------------------------
19480 REM---- ----- main program screen updating starts here ----------
19500 REM---- ----------------------------------------------------
19520 KEY(1) STOP :KEY(2) STOP :KEY(6) STOP :GOSUB 15940 '----time and buffer monitor routine
19540 IF KFINISH=1 THEN KFINISH=0 :LSW=0 :CLS :CLOSE :GOTO 980
19560 IF LSW=1 THEN LSW=0 :GOTO 4480
19580 KEY(1) ON :KEY(2) ON :KEY(6) ON
19600 IF KSHUT=0 THEN 20040 '----if emergency shut down flag off, skip here
19620 REM---- -- shut down check
19640 IF ADTNEW(1,4)=0 THEN 19700
19660 IF KSFLAG=4 THEN KSFLAG=0 :GOTO 20040
19680 GOTO 19740
19700 IF KSFLAG=4 THEN 20040
19720 KSFLAG=4 :SHUTCNT=120 :GOTO 20040 '----set flag and set timer to 5 min.
19740 IF ADTNEW(1,6)=0 THEN 19800 '---- f-fil. open ?
19760 IF KSFLAG=6 THEN KSFLAG=0 :GOTO 20040
19780 GOTO 19840
19800 IF KSFLAG=6 THEN 20040
19820 KSFLAG=6 :SHUTCNT=120 :GOTO 20040
19840 IF ADTNEW(1,1)*ADFS(1)<200 THEN 19900 '---- arc current <200 ma ?
19860 IF KSFLAG=1 THEN KSFLAG=0 :GOTO 20040
19880 GOTO 19940
19900 IF KSFLAG=1 THEN 20040
19920 KSFLAG=1 :SHUTCNT=120 :GOTO 20040
19940 IF ADTNEW(1,28)=0 THEN 20000 '---- ion beam current nil?
19960 IF KSFLAG=28 THEN KSFLAG=0
19980 GOTO 20040
20000 IF KSFLAG=28 THEN 20040
20020 KSFLAG=28 :SHUTCNT=120 :GOTO 20040
20040 IF KSFLAG=0 THEN 20100
20060 IF SHUTCNT<1 THEN GOSUB 24740 '----after time out goto shut down routine
20080 GOTO 20080 '----after shut off, stay here
20100 IF DOWNFLAG>>0 THEN 20200
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20120 IF UPFLAG>>0 THEN 20200
20140 IF DISPMODE=2 THEN 4460 '----if ion beam diplay is wanted, then goto beam display routine
20160 KEY(9) ON
20180 KEY(9) STOP
20200 IF NEWSET=0 THEN 19520 '----not new data ,bypass screen updating
20220 NEWSET=0 '----clear new data flag and update screen
20240 IF ISDCNT>>0 THEN LOCATE 24,75 :PRINT ISDCNT;
20260 IF UPFLAG>>0 THEN 20380
20280 IF DOWNFLAG>>0 THEN 20380
20300 IF IFLG9=1 THEN 21120
20320 IF IFLG9=2 THEN IFLG9=0 :GOTO 4460
20340 IF KRUN=0 THEN GOSUB 7860 '----if stop mode, monitor key enteries
20360 REM---- ------------ table1,table2 display updating --------------------
20380 MDROW=CSRLIN :MDCOL=POS(0)
20400 COLOR FCOLOR3,BCOLOR3
20420 IF IACTIVE=2 THEN 22320
20440 IF KADCHG=0 THEN 21120
20460 KADCHG=0 '----clear data change flag
20480 KEY(1) STOP :KEY(2) STOP :KEY(3) STOP :KEY(4) STOP :KEY(5) STOP :KEY(6) STOP
20500 IACT=0
20520 SCREEN 0,1,IACT,IVISUAL
20540 MJ=1 :MCOL=LDATACOR :IVM=IVISUAL+1 :KIACT=IACT+1
20560 FOR MI=1 TO 32
20580 MK=ADTOLD(KIACT,MI) :IF MK=0 THEN 20900
20600 IF MI>>16 THEN MJ=17 :MCOL=RDATACOR
20620 MROW=TOP-MJ+MI
20640 LOCATE MROW,MCOL
20660 ADTOLD(KIACT,MI)=0 :MK=ADTNEW(KIACT,MI)
20680 IF MI<>>3 THEN 20720
20700 IF MK=255 THEN ADTNEW(KIACT,MI)=254 :MK=254
20720 IF MK=255 THEN PRINT "error "; :GOTO 20960
20740 RDATAM=MK*ADFS(MI)
20760 IF MI=30 THEN KDATAM=INT(RDATAM) :REXP=KDATAM-8 :DATAM=RDATAM-KDATAM :DATAM=10 DATAM :KDATAM=CINT(DATAM) :PRINT
KDATAM;" X ";REXP; :GOTO 20960
20780 IF MI=29 THEN KDATAM=INT(RDATAM) :REXP=KDATAM-8 :DATAM=RDATAM-KDATAM :DATAM=10 DATAM :KDATAM=CINT(DATAM) :PRINT
KDATAM;" X ";REXP; :GOTO 20960
20800 IF MI>>30 THEN RDATAM=10 (2.5-RDATAM)*5 :GOTO 20880
20820 IF MI<>>8 THEN 20880
20840 IF RDATAM<.55 THEN RDATAM=10 (RDATAM*1.7067)*10 :GOTO 20880
20860 RDATAM=10 (RDATAM*1.09)*20 :GOTO 20880
20880 PRINT USING "###.##";RDATAM;
20900 MK=ADTNEW(KIACT,MI) :IF MI<>>27 THEN 20960
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20920 LOCATE 3,63 :COLOR FCOLOR1,BCOLOR2 :IF MK>>5 THEN PRINT " HIGH VOLT ON "; :COLOR FCOLOR3,BCOLOR3 :GOTO 20960
20940 COLOR FCOLOR3,BCOLOR3 :PRINT " HIGH VOLT OFF ";
20960 NEXT MI
20980 LOCATE 21,65 :PRINT USING "#.######";ACDOSE(KIACT);
21000 IF IACT=1 THEN 21120
21020 IF KOFF>>0 THEN IACT=1 :GOTO 20520
21040 SCREEN 0,1,IACTIVE,IVISUAL
21060 IF UPFLAG>>0 THEN 22080
21080 IF DOWNFLAG>>0 THEN 22080
21100 REM---- ----- auto source control ---------------------------
21120 ANODV=ADTNEW(IVM,3)*ADFS(3)
21140 IF KSAUTO=0 THEN 22080
21160 SFILI=DAREF(IVM,4)*ADFS(4)+DAREF(IVM,3)*ADFS3 '----source fil. current set point
21180 FFILI=DAREF(IVM,6)*ADFS(6) '----furnace fil. set point
21200 SFILV=ADTNEW(IVM,5)*ADFS(5) '----anode voltage
21220 ERROL2=ERROL1 :ERROL1=ERRNEW :SFILOLD=SFILNEW :ERRNEW=0
21240 ERRNEW=ANODV-ISAV :FFILOLD=FFILNEW
21260 REM---- --- ion source control gain ; SRCGAN, 1 + T / integral time constant ; SRCINT
21280 FILINC=SRCGAN*(SRCINT*ERRNEW-ERROL1*SRCDRV+DERIVT*ERROL2)
21300 IF FILINC>>2 THEN FILINC=2 :BEEP
21320 IF FILINC<-2 THEN FILINC=-2 :BEEP
21340 IF FILINC=0 THEN 22080
21360 IF FILINC>>0 THEN 21420
21380 IF SFILI>>6 THEN 21460
21400 GOTO 21880 '----f-fil control, reduce f-fil current
21420 IF SFILI<18 THEN 21460
21440 GOTO 21880 '----f-fil control, increase f-fil. current
21460 SFILNEW=SFILOLD+FILINC
21480 REM---- ---- source filament current control ; d/a ch3,ch4 -- base set point ; ch4 (fs = 20 amp, set by multiples of
2.5 amp), high resolution set point ; ch3 ( fs = 2.5 amp)
21500 KFIL4=INT(SFILNEW/2.5) '----ch4 base set point
21520 IREF4=KFIL4*2.5/ADFS(4) :SFIL3=SFILNEW-KFIL4*2.5 :IREF3=SFIL3/ADFS3
21540 IF IREF4=DAREF(IVM,4) THEN 21680
21560 IF IREF4>>255 THEN IREF4=255
21580 DAREF(IVM,4)=IREF4
21600 ICON4=IREF4*DAFTR(4)+DASHFT(4)
21620 IF ICON4>>127 THEN ICON4=127
21640 PRINT #1,CHR$(KCONT);CHR$(3);CHR$(ICON4); '----send out ch4 control set point
21660 PRINT #1,CHR$(KCONT);CHR$(27);CHR$(ICON4); '----send out ch4 control set point
21680 IF IREF3=DAREF(IVM,3) THEN 21820 '----if high resolution not changed skip here
21700 IF IREF3>>255 THEN IREF3=255
21720 DAREF(IVM,3)=IREF3
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21740 ICON3=IREF3*DAFTR3+DASHFT(3)
21760 IF ICON3>>127 THEN ICON3=127
21780 PRINT #1,CHR$(KCONT);CHR$(2);CHR$(ICON3); '----send out ch3 control set point
21800 PRINT #1,CHR$(KCONT);CHR$(26);CHR$(ICON3); '----send out ch3 control set point
21820 LOCATE 8,LREFCOR :PRINT USING "###.##";SFILNEW;
21840 GOTO 22080
21860 REM---- ---- furnace filament current control
21880 FFILNEW=FFILOLD+FILINC
21900 ICNEW=FFILNEW/ADFS(6) :MIDR=CINT(ICNEW) :MDAC=ICNEW*DAFTR(6)+DASHFT(6) :IF MDAC>>127 THEN MDAC=127 :ICNEW=127
21920 ICOLD=DAREF(IVM,6)*DAFTR(6)+DASHFT(6) :IF ICOLD=ICNEW THEN 22080
21940 DAREF(1,6)=ICNEW
21960 DAREF(2,6)=ICNEW
21980 PRINT #1,CHR$(KCONT);CHR$(5);CHR$(MDAC);
22000 PRINT #1,CHR$(KCONT);CHR$(29);CHR$(MDAC);
22020 LOCATE 10,LREFCOR :PRINT USING "###.##";FFILNEW;
22040 REM---- ---- write ion source control data into file "ISDATA" on super drive
22060 REM---- ---- ISDATA file starts when AUTOSOURCE (F7) is on --- date,time,control gain, integral time, derivtive time
is writen on the head
22080 IF ISDCNT<1 THEN 22200
22100 SFNEW=DAREF(IVM,4)*ADFS(4)+DAREF(IVM,3)*ADFS3
22120 WRITE#4,ANODV,SFNEW
22140 WRITE#3,ANODV,SFNEW :ISDCNT=ISDCNT-1
22160 IF ISDCNT>>0 THEN 22200
22180 CLOSE 3,4 :LOCATE 24,1 :COLOR FCOLOR1,BCOLOR1 :PRINT "F8-anode V rec.off"; :BEEP :COLOR FCOLOR3,BCOLOR3 :KEY(8) ON
22200 IF CONTCNT>>0 THEN CONTCNT=CONTCNT-1 :GOTO 19520
22220 IF UPFLAG>>0 THEN LOCATE CONTROW,CONTCOL :GOTO 8500
22240 IF DOWNFLAG>>0 THEN LOCATE CONTROW,CONTCOL :GOTO 8500
22260 KEY(1) ON :KEY(2) ON :KEY(3) ON :KEY(4) ON :KEY(5) ON :GOTO 19520
22280 REM---- -------------------------------------------------------
22300 REM---- -------- on/off switch display update -------------------------
22320 MK=ADTNEW(1,27)
22340 COLOR FCOLOR1,BCOLOR2 :IF MK<5 THEN 22400
22360 IF START$="XXX" THEN LOCATE 5,70 :START$=TIME$ :PRINT START$
22380 LOCATE 3,63 :PRINT " HIGH VOLT ON "; :COLOR FCOLOR3,BCOLOR3 :GOTO 22420
22400 LOCATE 3,63 :COLOR FCOLOR3,BCOLOR3 :PRINT " HIGH VOLT OFF ";
22420 IF NFCHG=0 THEN 19520
22440 KEY(1) STOP :KEY(2) STOP :KEY(3) STOP :KEY(4) STOP :KEY(6) STOP :SCREEN 0,1,IACTIVE,IVISUAL
22460 NFCHG=0 :FOR MI=1 TO 16 :MK=NFTOLD(MI) :IF MK=0 THEN 22700
22480 NFTOLD(MI)=0 :MROW=NFTOP-1+MI :MCOL=NFDATACOR
22500 LOCATE MROW,MCOL
22520 IF NFTBL(MI)=255 THEN PRINT "error "; :BEEP :GOTO 22700
22540 IF MI<>>3 THEN 22600
```

```
22560 IF NFTBL(MI)=1 THEN PRINT "CLOSE "; :GOTO 22700
22580 PRINT "OPEN "; :GOTO 22700
22600 IF MI<>>8 THEN 22660
22620 IF NFTBL(MI)=1 THEN PRINT "OPEN "; :GOTO 22700
22640 PRINT "CLOSED"; :GOTO 22700
22660 IF NFTBL(MI)=1 THEN PRINT " ON "; :GOTO 22700
22680 IF NFTBL(MI)=0 THEN PRINT " OFF ";
22700 NEXT
22720 LOCATE 13,70 :PRINT USING "#.######";ACDOSE(1);
22740 LOCATE 14,70 :PRINT USING "#.######";ACDOSE(2);
22760 KEY(1) ON :KEY(2) ON :KEY(3) ON :KEY(4) ON :KEY(6) ON :GOSUB 15940 :GOTO 20140
22780 REM---- ------- main program over here --------------------------
22800 REM---- --------------------------------------------------------
22820 REM---- ------- time region change
22840 HREGION=HREGION+1
22860 IF HREGION>>5 THEN HREGION=0
22880 RETURN
22900 REM---- --------------------------------------------------------
22920 REM---- ------- time region change
22940 HREGION=HREGION-1
22960 REM---- --------------------------------------------------------
22980 IF HREGION<0 THEN HREGION=5
23000 RETURN
23020 REM---- --------------------------------------------------------
23040 REM---- ------- time scale change, 1 data display per 10 sec or 1 min.
23060 IF KEXP=1 THEN KEXP=0 :GOTO 23100
23080 IF KEXP=0 THEN KEXP=1
23100 RETURN
23120 REM---- ---- switch display mode to table display
23140 DISPMODE=2 :RETURN
23160 REM---- --- F7--- ion source auto control --- control Sfil,Ffil to keep anode current>>500 ma and anode voltage
between 70 and 120 volt
23180 IF IVISUAL=2 THEN 23320
23200 IVM=IVISUAL+1
23220 XROW=CSRLIN :YCOL=POS(0)
23240 KSAUTO=KSAUTO-1
23260 IF KSAUTO=0 THEN 23300
23280 KSAUTO=1 :COLOR FCOLOR3,BCOLOR3 :LOCATE 25,58 :PRINT " F7-AUTOSOURCE "; :KSRCE=0
:SFILNEW=DAREF(IVM,4)*ADFS(4)+DAREF(IVM,3)*ADFS3 :FFILNEW=DAREF(IVM,6)*ADFS(6) :GOTO 23320
23300 LOCATE 24,60 :COLOR FCOLOR1,BCOLOR1 :LOCATE 25,58 :PRINT " F7-AUTOSOURCE "; :ERRNEW=0
23320 LOCATE XROW,YCOL :RETURN
23340 REM---- ---- F8 : control data collection initialization
```

```
23360 IF ISDCNT>>0 THEN 23500
23380 ISDCNT=540 :KEY(8) OFF :OPEN "c :isdata1" FOR OUTPUT AS #3 :KSA$="ON" :IF KSAUTO=0 THEN KSA$="OFF"
23400 WRITE#3,DATE$,TIME$,MAT$(1),KSA$,ISAV,SRG,INTM,DERIVT
23420 OPEN "c :isdata2" FOR APPEND AS #4
23440 WRITE#4,DATE$,TIME$,MAT$(1),KSA$,ISAV,SRG,INTM,DERIVT
23460 LOCATE 24,1 :PRINT "F8-anode V rec. on";
23480 KEY(9) ON
23500 RETURN
23520 REM---- --- F9 : ion source control data display (F9)
23540 IF ISDCNT>>0 THEN 24300
23560 IF IFLG9>>0 THEN IFLG9=2 : GOTO 24300
23580 IFLG9=1
23600 SCREEN 2 :CLS
23620 OPEN "c :isdata1" FOR INPUT AS #3
23640 INPUT#3,D$,T$,MA$,AUTO$,ANOD,GAIN,TI,TD
23660 LOCATE 1,10 :PRINT "ION SOURCE ANODE VOLTAGE CONTROL"
23680 LOCATE 2,1 :PRINT D$,T$,"ion source material :";MA$;
23700 FAMP=ADTNEW(1,6)*ADFS(6)
23720 LOCATE 3,1 :PRINT "anode current : 600 mA , furnace fil."; :PRINT USING "##.##";FAMP;
23740 LOCATE 4,1
23760 PRINT "anode volt ref. :";ANOD;"volt","PID G/Ti/Td";
23780 IF AUTO$="OFF" THEN PRINT " -- OFF --"; :GOTO 23820
23800 PRINT GAIN;"/";TI;"/";TD;
23820 IYBASE=190 :IXBASE=50 :IXINC=50 :IYINC=50 :IXEND=592 :IYAOLD=190 :IYFOLD=190
23840 LINE(IXBASE,40)-(IXBASE,IYBASE) :LINE -(IXEND,IYBASE)
23860 FOR I=1 TO 11 :IX=IXBASE+50*I :PSET(IX,IYBASE) :DRAW "u5" :NEXT
23880 FOR I=0 TO 11 :X=6+6*I :LOCATE 25,X :MX=50*I :PRINT MX; :NEXT
23900 FOR I=1 TO 6 :IY=IYBASE-25*I :PSET(IXBASE,IY) :DRAW "r7" :NEXT
23920 FOR I=0 TO 6 :Y=24-3*I :LOCATE Y,1 :MY=50*I :PRINT MY; :NEXT
23940 LOCATE 5,1 :PRINT "anode volt"; :LOCATE 5,25 :PRINT "sampling interval T= 0.5 sec."; :LOCATE 25,77 :PRINT "x T";
23960 LINE(IXEND,40)-(IXEND,IYBASE)
23980 FOR I=1 TO 5 :IY=IYBASE-30*I :PSET (IXEND,IY) :DRAW "17" :NEXT
24000 FOR I=0 TO 5 :IY=CINT(24-3.7*I) :LOCATE IY,76 :MY=10+2*I :PRINT MY; :NEXT
24020 LOCATE 5,70 :PRINT "Fil. Amp.";
24040 IY=IYBASE-ISAV/2
24060 IF IY<40 THEN IY=40
24080 LINE(IXBASE,IY)-(IXEND,IY)
24100 IX=IXBASE-1
24120 INPUT#3,ANOD,SSFIL
24140 IF EOF(3) THEN CLOSE 3 :GOTO 24300
24160 IYFNEW=IYBASE-(SSFIL-10)*15 :IF IYFNEW>>IYBASE THEN IYFNEW=IYBASE
24180 IYANEW=IYBASE-ANOD/2
```

```
24200 IX=IX+1
24220 IF IX>>540 THEN CLOSE 3 :GOTO 24300
24240 LINE(IX,IYFOLD)-(IX,IYFNEW) :IYFOLD=IYFNEW
24260 LINE (IX,IYAOLD)-(IX,IYANEW) :IYAOLD=IYANEW
24280 GOTO 24120
24300 RETURN
24320 REM------- F10 -- ion beam data recording on/off
24340 IF IBREC=1 THEN IBREC=0 :CLOSE 5,6 :LOCATE 24,40 :PRINT "F10-beam rec. off"; :GOTO 24480
24360 IBREC=1
24380 OPEN "c :ibten1" FOR APPEND AS #5
24400 OPEN "c :ibten2" FOR APPEND AS #6
24420 WRITE#5,DATE$,TIME$,MAT$(1),"ion beam current 10 sec. sampling"
24440 WRITE#6,DATE$,TIME$,MAT$(2),"ion beam current 10 sec. sampling"
24460 LOCATE 24,40 :PRINT "F10-beam rec. on ";
24480 RETURN
24500 REM---- ---- deposition material switching, from #1 to #2
24520 IF KOFF=0 THEN RETURN
24540 PRINT #1, CHR$(KLENGTM);CHR$(1);CHR$(0); '----turn off material #1
24560 PRINT #1, CHR$(KLENGTM);CHR$(2);CHR$(127); '----turn on material #2
24580 BEEP
24600 RETURN
24620 REM---- ---- deposition material switching, from #2 to #1
24640 IF KOFF=0 THEN RETURN
24660 PRINT #1, CHR$(KLENGTM);CHR$(2);CHR$(0); '----turn off material #2
24680 PRINT #1, CHR$(KLENGTM);CHR$(1);CHR$(127); '----turn on material #1
24700 BEEP
24720 RETURN
24740 REM---- ---- accumulated deposition charge reached the planned value, turn off arc, beam energy and other power
sources
24760 OPEN "b :messg" FOR APPEND AS #8
24780 PRINT#8,DATE$;",";TIME$;",";
24800 LPRINT DATE$;",";TIME$;",";
24820 CLS
24840 IF KSFLAG<>>1 THEN 24940
24860 PRINT#8,"arc has deminished, system shut down activated,";
24880 LPRINT "arc has deminished, system shut down activated,";
24900 PRINT "arc has deminished, system shut down activated,";
24920 GOTO 25220
24940 IF KSFLAG<>>4 THEN 25040
24960 PRINT#8,"source filament burnt, system shut down activated,";
24980 LPRINT "source filament burnt, system shut down activated,";
25000 PRINT "source filament burnt, system shut down activated,";
```

```
25020 GOTO 25220
25040 IF KSFLAG<>6 THEN 25140
25060 PRINT#8,"furnace filament burnt, system shut down activated,";
25080 LPRINT "furnace filament burnt, system shut down activated,";
25100 PRINT "furnace filament burnt, system shut down activated,";
25120 GOTO 25220
25140 IF KSFLAG<>28 THEN 25220
25160 PRINT#8,"ion beam current deminished for more than one minute,";
25180 LPRINT "ion beam current deminished for more than one minute,";
25200 PRINT "ion beam current deminished for more than one minute,";
25220 PRINT#8,MAT$(1)",";  :FOR I=1 TO 32 :RDATA=ADTNEW(1,I)*ADFS(I) '----save data
25240 PRINT#8,I;",";  :PRINT#8,USING "###.##,";RDATA;  :NEXT
25260 LPRINT,MAT$(1)",";  :FOR I=1 TO 32 :RDATA=ADTNEW(1,I)*ADFS(I) '----save data
25280 LPRINT I,RDATA;CH$(I) :NEXT
25300 IF KOFF=0 THEN 25400
25320 PRINT#8,MAT$(2);",";  :FOR I=1 TO 32 :RDATA=ADTNEW(2,I)*ADFS(I) '----save data
25340 PRINT#8,I;",";  :PRINT#8,USING "###.##,";RDATA;  :NEXT
25360 LPRINT,MAT$(2)",";  :FOR I=1 TO 32 :RDATA=ADTNEW(2,I)*ADFS(I) '----save data
25380 LPRINT I,RDATA;CH$(I) :NEXT
25400 KSAUTO=0 '---- turn off ion source control
25420 PRINT #1, CHR$(KCONT);CHR$(63);CHR$(0); '----turn off high voltage
25440 PRINT "ion beam deposition stopped and high voltage is turned off"
25460 PRINT " To restart system, hit any key while beep is on." :IB=0
25480 A$=INKEY$ :BEEP :IB=IB+1
25500 IF A$<>"" THEN 26040
25520 IF IB<50 THEN 25480
25540 PRINT #1, CHR$(KCONT);CHR$(0);CHR$(0);
25560 PRINT #1, CHR$(KCONT);CHR$(24);CHR$(0);
25580 PRINT #1, CHR$(KCONT);CHR$(3);CHR$(0);
25600 PRINT #1, CHR$(KCONT);CHR$(4);CHR$(0);
25620 PRINT #1, CHR$(KCONT);CHR$(27);CHR$(0);
25640 PRINT #1, CHR$(KCONT);CHR$(28);CHR$(0);
25660 PRINT #1, CHR$(KCONT);CHR$(5);CHR$(0);
25680 PRINT #1, CHR$(KCONT);CHR$(6);CHR$(0);
25700 PRINT #1, CHR$(KCONT);CHR$(29);CHR$(0);
25720 PRINT #1, CHR$(KCONT);CHR$(30);CHR$(0);
25740 PRINT #1, CHR$(KCONT);CHR$(8);CHR$(0);
25760 PRINT #1, CHR$(KCONT);CHR$(32);CHR$(0);
25780 PRINT #1, CHR$(KCONT);CHR$(18);CHR$(0);
25800 PRINT #1, CHR$(KCONT);CHR$(42);CHR$(0);
25820 PRINT #1, CHR$(KCONT);CHR$(19);CHR$(0);
25840 PRINT #1, CHR$(KCONT);CHR$(43);CHR$(0);
```

```
25860 PRINT #1, CHR$(KCONT);CHR$(20);CHR$(0);
25880 PRINT #1, CHR$(KCONT);CHR$(44);CHR$(0);
25900 PRINT #1, CHR$(KCONT);CHR$(21);CHR$(0);
25920 PRINT #1, CHR$(KCONT);CHR$(9);CHR$(0);
25940 PRINT #1, CHR$(KCONT);CHR$(45);CHR$(0); '----turn off focus power
25960 PRINT #1, CHR$(KCONT);CHR$(33);CHR$(0); '----turn off focus power
25980 LPRINT "deposition over at ";TIME$;"---";DATE$
26000 CLS
26020 LOCATE 10,10 :PRINT "********* SYSTEM WILL BE RESTARTED SOON *********** "
26040 KFINISH=1
26060 CLOSE #8 :RETURN
26080 REM---- ------ operation reference point settting store routine( mat. #1)
26100 OPEN "b :setpoint" FOR APPEND AS #7
26120 PRINT#7,DATE$,TIME$,MAT$(1),"reference set points"
26140 FOR KRCH=1 TO 24 :IF DAFTR(KRCH)=0 THEN 26220
26160 CRDATA=DAREF(1,KRCH)*ADFS(KRCH)
26180 PRINT#7,KRCH;",";
26200 PRINT#7,USING"###.##,";CRDATA;
26220 NEXT :CLOSE #7
26240 RETURN
26260 REM---- ------ operation reference point settting store routine(mat. #2)
26280 OPEN "b :setpoint" FOR APPEND AS #7
26300 PRINT#7,DATE$,TIME$,MAT$(2),"reference set points"
26320 FOR KRCH=1 TO 24 :IF DAFTR(KRCH)=0 THEN 26400
26340 CRDATA=DAREF(2,KRCH)*ADFS(KRCH)
26360 PRINT#7,KRCH;",";
26380 PRINT#7,USING"###.##,";CRDATA;
26400 NEXT :CLOSE #7
26420 RETURN
```

# XIII. APPENDIX III

MASTER COMPUTER ION BEAM DEPOSITION SYSTEM START-UP AND ION SOURCE OUTGASSING ROUTINE

```
50 REM---- *************************************************************
100 REM---- Ion Beam Deposition System Start-Up and Ion Source Outgassing Routine
112 REM----
114 REM----
116 REM---- Written by Jaeshin Ahn
118 REM---- Dept. of Electrical Engineering
120 REM---- University of Alberta
122 REM---- January, 1984
124 REM----
126 REM----
150 REM---- ************************************************************
200 DEFINT I-N
250 DIM NFMTBL(16),NFMOLD(16),NFM(16) '----sw table,reference,new,old
300 DIM CH$(32),CHNAM$(32) '----channel names,for display,for mesaage
350 DIM NFCH$(16),NFM$(16) '----sw channel names
400 DIM NFTBL$(16),AREF$(36)
450 DIM NFTBL(16),NFTOLD(16) '----sw data , current ,old
500 DIM TEMPO(80)
550 DIM DAFTR(24),DASHFT(24),DAREF(24),ADTNEW(32),SDTOLD(32),ADFS(32),DACONT(24)
600 DIM XL(10),YL(2,4)
650 KRUN=1 :BCOLOR1=1 :FCOLOR1=15 :BCOLOR2=4 :FCOLOR2=15 :BCOLOR3=0 :FCOLOR3=14
700 KPCBAD=246 :KCONT=249 '----master reference change,pc error
750 KHENGTM=241 :KLENGTM=242 :KOFFTM=243 '----beam time for high,low enrgy, beam off time
800 KTXCTL=247 :KFIRST=240 :KSECOND=241 :KLAST=242 '----data packet start and end indicator
850 IBCNT=0 :IBMINCNT=0 :IBTENCNT=0 :IBMCNT=0
900 FOR I=1 TO 32 :ADFS(I)=1 :NEXT :FOR I=1 TO 24 :DAFTR(I)=.5 :DASHFT(I)=0 :DACONT(I)=1 :NEXT
950 ADFS(1)=1000/256 :ADFS(4)=20/256*1.09 :ADFS(5)=18/256 :ADFS(6)=25/256 :ADFS(7)=15/256 :ADFS(8)=3/256 :ADFS(3)=500/256
:ADFS(30)=5/256 :ADFS(31)=2.5/256 :ADFS(32)=2.5/256
960 ADFS(23)=15/256
1000 SCREEN 2 :SCREEN 0,1,0,0 :COLOR FCOLOR1,BCOLOR1
1050 CLS :LOCATE 24,10 :PRINT "NOW PROGRAM BEING EXECUTED, PLEASE DO NOT DISTURB ME."
1100 DEF SEG=0
1150 FOR I=1 TO 32 :CH$(I)=" " :NEXT
1200 FOR I=1 TO 16 :NFCH$(I)=" " :NEXT
1250 REM---- ------ MASTER DISPLAY TABLE NOTE ASSIGN
1300 CHNAM$(1)="ANODE CURRENT " :CHNAM$(2)="ION BEAM ENERGY"
1350 CHNAM$(22)="EINZEL LENS FOCUSING" :CHNAM$(4)="ION SOURCE FILAMENT POWER"
1400 CHNAM$(5)="ION SOURCE FILAMENT POWER" :CHNAM$(6)="front furnace amp."
1450 CHNAM$(7)="rear furnace amp." :CHNAM$(8)="GAS-HANDLING PLANT PRESSURE"
1500 CHNAM$(9)="MAGNET " :CHNAM$(10)="MAGNET"
1550 CHNAM$(11)="SHIM BALANCE" :CHNAM$(12)="SHIM R 1 "
1600 CHNAM$(13)="SHIM R 2 " :CHNAM$(14)="SHIM R 3 "
```

```
1650 CHNAM$(15)="SHIM L 1 " :CHNAM$(16)="SHIM L 2 "
1700 CHNAM$(17)="SHIM L 3" :CHNAM$(18)="SHIM MID "
1750 CHNAM$(19)="VELOCITY FILTER " :CHNAM$(20)="VERTICAL DEFLECTION "
1800 CHNAM$(21)="HORIZONTAL DEFLECTION " :CHNAM$(22)=" "
1850 CHNAM$(23)="rear furnace volt" :CHNAM$(24)=" " :CHNAM$(3)="ION SOURCE ANODE "
1900 CHNAM$(26)=" " :CHNAM$(27)=" " :CHNAM$(28)="ION BEAM CURRENT"
1950 CHNAM$(29)="TARGET CHAMBER ION GAUGEG "
2000 CHNAM$(30)=" SOURCE CHAMBER ION GAUGE "
2050 CHNAM$(31)=" TARGET CHAMBER FORELINE PRESSURE "
2100 CHNAM$(32)=" SOURCE CHAMBER FORELINE PRESSURE "
2150 CH$(1)="mA ANODE CURRENT" :CH$(2)="eV BEAM ENERGY"
2200 CH$(22)="KV FOCUS" :CH$(4)="A SOURCE FIL" :CH$(5)="V SOURCE FIL"
2250 CH$(6)="A front furnace" :CH$(7)="A rear furnace" :CH$(8)="mTORR GHP"
2300 CH$(9)="A MAGNET" :CH$(10)="V MAGNET" :CH$(11)="V SHIM BALANCE"
2350 CH$(12)="V SHIM R 1" :CH$(13)="V SHIM R 2" :CH$(14)="V SHIM R 3"
2400 CH$(15)="V SHIM L 1" :CH$(16)="V SHIM L 2" :CH$(17)="V SHIM L 3"
2450 CH$(18)="V SHIM MID" :CH$(19)="V VELO. FLTR" :CH$(20)="V VERT. DEFL."
2500 CH$(21)="V HORZ. DEFL" :CH$(23)="V rear furnace "
2550 CH$(3)="V SOURCE ANODE"
2600 CH$(28)="uA BEAM CURRENT" :CH$(29)="Torr TARGET CHAMBER" :CH$(30)="Torr SOURCE CHAMBER" :CH$(31)="mTorr T CH.
FORELINE" :CH$(32)="mTorr S CH. FORELINE"
2650 REM---- -------- A/D D/A CHANNEL MNEUMONIC ASSIGN
2700 ANODI=1 :BEAMV=2 :FOCUSV=3 :SFILI=4 :SFILV=5 :FFILI=6 :FFILV=7 :IGGHP=8
2750 MAGI=9 :MAGV=10 :SHMBAL=11 :SHMR1=12 :SHMR2=13 :SHMR3=14 :SHML1=15 :SHML2=16
2800 SHML3=17 :SHMMID=18 :VELOV=19 :VDEF=20 :HDEF=21
2850 IGFILS=23 :IGFILT=24 '----ion gauge filament sensing
2900 ANODV=25 :BEAMI=28 '----anode voltage and beam current
2950 IGPT=29 :IGPS=30 :IGTFL=31 :IGSFL=32 '----ion gauge pressure, chamber, forelin
3000 REM---- -------- ON/OFF SWITCH CONTROLLER CHANNEL ASSIGN
3050 RPSCH=1 :DPSCH=2 :RPTCH=3 :DPTCH=4 :TURBOP=5 :TURBOH=6 :GATEV=7 :RPGHP=8 :HIVOLT=9 :RACK1=10 :RACK2=11 :RACK3=12
3100 FOR I=1 TO 16 :NFCH$(I)=" " :NEXT
3150 NFCH$(1)="ROTARY PUMP, SOURCE CH." :NFCH$(2)="DIFFUSION PUMP, SOURCE CH." :NFCH$(3)="ROTARY PUMP, TARGET CH."
3160 NFCH$(4)="DIFFUSION PUMP, TURBO FL" :NFCH$(5)="TURBO MOL. PUMP" :NFCH$(6)="TURBO, HEATER" :NFCH$(7)="GATE
VALVE,TURBO" :NFCH$(8)="ROTARY PUMP,GHP
3200 TOP=5 :BOTM=20 :LREFCOR=6 :RREFCOR=48 :LDATACOR=13 :RDATACOR=55 :HALF=40
3250 NFTOP=7 :NFBOT=22 :NFREFCOR=35 :NFDATACOR=41
3300 REM---- ---------------------------------------------------
3350 REM---- --- dimension declaration,mneumonic and command assignment
3400 REM---- ---------------------------------------------------
3450 FOR I=1 TO 16 :NFM$(I)="off" :NEXT
3500 CLOSE :KEY OFF
3550 OPEN "COM1:2400,N,8,1,RS,CS,DS,CD" AS #1
```

```
3600 OPEN "SCRN :"FOR OUTPUT AS #2
3650 COM(1) ON
3700 LOCATE 5,15 :PRINT #2,"MASTER STARTING POINT SELECTION "
3750 LOCATE 9,3
3800 PRINT #2,"1 ; Start Ion Beam Deposition."
3850 LOCATE 11,3
3900 PRINT #2,"2 ; Start Ion Source Outgassing."
3950 LOCATE 15,3
4000 PRINT "ENTER 1-2 "
4050 A$=INKEY$ :IF A$="" THEN 4050
4100 IF A$="2" THEN 4400
4150 IF A$="1" THEN STOP
4200 PRINT "WRONG ENTRY, TRY AGAIN" :GOTO 4000
4250 REM---- -----------------------------------------------
4300 REM---- ---- slave computer initialization starts here
4350 REM---- -----------------------------------------------
4400 CLS :LOCATE 3,10 :PRINT "TURN ON SLAVE COMPUTER AND HIT ANY KEY WHEN READY"
4450 A$=INKEY$ :IF A$="" THEN 4450
4490 ON ERROR GOTO 4500
4500 N=LOC(1) :IF N>>0 THEN A$=INPUT$(N,1) '----CLEAR INPUT BUFFER
4510 ON ERROR GOTO 0
4550 BEEP :PRINT #1,CHR$(KTXCTL);CHR$(KTXCTL);CHR$(KTXCTL); '----SEND MEMORY TEST RESULT REQUEST
4565 FOR I=1 TO 3000 :NEXT
4600 N=LOC(1) :IF N=0 THEN 4550
4650 A$=INPUT$(1,1) :N=ASC(A$) :IF N=247 THEN 4660
4652 IF N<>>KFIRST THEN 4650
4653 GOTO 6450
4660 N=LOC(1) :IF N=0 THEN 4660
4670 A$=INPUT$(1,1) :N=ASC(A$)
4700 K1=N AND 1 :K2=N AND 2 :K3=N AND 4 :K4=N AND 8 :K5=N AND 16 :K6=N AND 32
4750 PRINT " MEMORY TEST RESULTS "
4800 PRINT "2K MEMORY CHIP #1 TESTED "; :IF K1<>>0 THEN PRINT " OK" :GOTO 4900
4850 PRINT "FAILED"
4900 PRINT "2K MEMORY CHIP #2 TESTED "; :IF K2<>>0 THEN PRINT " OK" :GOTO 5000
4950 PRINT "FAILED"
5000 PRINT "2K MEMORY CHIP #3 TESTED "; :IF K3<>>0 THEN PRINT " OK" :GOTO 5100
5050 PRINT "FAILED"
5100 PRINT "2K MEMORY CHIP #4 TESTED "; :IF K4<>>0 THEN PRINT " OK" :GOTO 5200
5150 PRINT "FAILED"
5200 PRINT "2K MEMORY CHIP #5 TESTED "; :IF K5<>>0 THEN PRINT " OK" :GOTO 5300
5250 PRINT "FAILED"
5300 PRINT "2K MEMORY CHIP #6 TESTED "; :IF K6<>>0 THEN PRINT " OK" :GOTO 5750
```

```
5350 PRINT "FAILED"
5400 GOSUB 5750
5450 GOTO 6450
5500 REM---- --------------------------------------------------
5550 REM---- ---- slave computer memory test report over
5600 REM---- --------------------------------------------------
5650 REM---- ---- subroutine to get data from slave and put data into array
5700 REM---- --------------------------------------------------
5750 N=LOC(1) :IF N>>O THEN A$=INPUT$(N,1)
5800 PRINT #1,CHR$(KTXCTL);CHR$(KTXCTL);CHR$(KTXCTL);
5850 N=LOC(1) :IF N<51 THEN 5850 '----32+16+3 BYTES READY ?
5900 N1=ASC(INPUT$(1,1)) :IF N1=KFIRST THEN 6050
5950 N=LOC(1) :IF N>>O THEN 5900
6000 GOTO 5800 '----TRY TO GET DATA AGAIN
6050 N2=ASC(INPUT$(1,1)) :IF N2=KSECOND THEN 6150
6100 N=LOC(1) :A$=INPUT$(1,N) :GOTO 5800 '----if second byte not correct try again
6150 NMOD=ASC(INPUT$(1,1)) '----beam switching mode
6160 N=LOC(1) :IF N<49 THEN A$=INPUT$(1,N) :GOTO 5800
6200 FOR I=1 TO 32
6250 K=ASC(INPUT$(1,1)) :ADTNEW(I)=K :NEXT
6300 FOR I=1 TO 16
6350 K=ASC(INPUT$(1,1)) :NFTBL(I)=K :NEXT
6400 K=ASC(INPUT$(1,1)) :IF K<>>KLAST THEN 5800
6405 REM---- --------------------------------------------------
6410 RETURN '----data update subroutine over
6415 REM---- --------------------------------------------------
6450 LOCATE 22,10 :PRINT " "; :LOCATE 22,10 :PRINT "all the pumps are running ? (y/n) ";
6500 A$=INKEY$ :IF A$="" THEN 6500
6550 IF A$="y" OR A$="Y" THEN 12850
6750 REM---- --- system pumps starts
6800 REM---- --------------------------------------------------
6850 KS=NFTBL(RPSCH) :IF KS=1 THEN PRINT "SOURCE CHAMBER ROTARY PUMP RUNNUNG" :GOTO 7750
6900 IF KS<255 THEN 7250
6950 PRINT "CONTROL ERROR, CHECK FUSE OR CONTROLLER MALFUNCTION . ENTER YES WHEN PROBLEM RECTIFIED "
7000 A$=INKEY$ :IF A$="" THEN 7000
7050 B$=INKEY$ :IF B$="" THEN 7050
7100 C$=INKEY$ :IF C$="" THEN 7100
7150 IF A$="Y" AND B$="E" AND C$="S" THEN GOSUB 5750 :GOTO 6850
7200 PRINT "WRONG ENTRY, TRY AGAIN" :GOTO 6900
7250 IF KS=O THEN PRINT "TO TURN ON SOURCE CHAMBER ROTARY PUMP TYPE IN YES "
7300 A$=INKEY$ :IF A$="" THEN 7350
7350 B$=INKEY$ :IF B$="" THEN 7350
```

```
7400 C$=INKEY$ :IF C$="" THEN 7400
7450 IF A$="Y" AND B$="E" AND C$="S" THEN 7550
7500 PRINT "WRONG ENTRY TRY AGAIN IF YOU WANT TO TURN ON RP" :GOTO 6850
7550 KRP=RPSCH+64 :PRINT #1,CHR$(KCONT);CHR$(KRP);CHR$(1);
7600 FOR I=1 TO 5000 :NEXT '----delay loop to make sure pump is turned on
7650 GOSUB 5750 '----read switch status again
7700 GOTO 6850 '----check if pump is on, if not try to turn on again
7750 KS=NFTBL(RPTCH) :IF KS=1 THEN PRINT "TARGET CHAMBER ROTARY PUMP IS RUNNING" :GOTO 8550
7800 IF KS<255 THEN 8150
7850 PRINT "CONTROL ERROR, CHECK FUSE OR CONTROLLER MALFUNCTION, ENTER YES WHEN PROBLEM REM---- OVED"
7900 A$=INKEY$ :IF A$="" THEN 7900
7950 B$=INKEY$ :IF B$="" THEN 7950
8000 C$=INKEY$ :IF C$="" THEN 8000
8050 IF A$="Y" AND B$="E" AND C$="S" THEN GOSUB 5750 :GOTO 7750
8100 PRINT "WRONG ENTRY, TRY AGAIN" :GOTO 7750
8150 IF KS=0 THEN PRINT "TO TURN ON TARGET CHAMBER ROTARY PUMP TYPE IN YES"
8200 A$=INKEY$ :IF A$="" THEN 8200
8250 B$=INKEY$ :IF B$="" THEN 8250
8300 C$=INKEY$ :IF C$="" THEN 8300
8350 IF A$="Y" AND B$="E" AND C$="S" THEN 8450
8400 PRINT "WRONG ENTRY. TRY AGAIN" :GOTO 8150
8450 KRP=RPTCH+64 :PRINT #1,CHR$(KCONT);CHR$(KRP);CHR$(1);
8500 FOR I=1 TO 5000 :NEXT :GOSUB 5750 :GOTO 7750
8550 IFLMAX=10 '----foreline pressure limit
8600 CLS :PRINT "NOW ROTARY PUMP FOR BOTH CHAMBERS ARE RUNNUNG"
8650 KCH2=TURBOP+64 :KCH1=DPSCH+64
8700 GOSUB 5750 :KS1=NFTBL(KCH1) :KS2=NFTBL(KCH2) :KFL1=ADTNEW(IGSFL) :KFL2=ADTNEW(IGTFL)
8750 IF KFL1<IFLMAX THEN 9250
8800 IF KFL2<IFLMAX THEN 8900
8850 FOR I=1 TO 10000 :NEXT :GOTO 8700
8900 IF KS2=0 THEN PRINT #1,CHR$(KCONT);CHR$(KCH2);CHR$(1); :GOTO 8850
8950 IF KS2=255 THEN PRINT "TURBO PUMP CONTROL ERROR, CHECK FUSE OR CONTROLLER , TYPE Y WHEN READY" :GOTO 9050
9000 GOTO 9200
9050 A$=INKEY$ :IF A$="" THEN 9050
9100 IF A$<>>"Y" THEN 8950
9150 GOTO 8700
9200 IF KS2=1 THEN 8850
9250 IF KFL2<IFLMAX THEN 9650
9300 IF KS1=0 THEN PRINT #1,CHR$(KCONT);CHR$(KCH1);CHR$(1); :GOTO 8850
9350 IF KS1=1 THEN 8850
9400 IF KS1=255 THEN PRINT "SOURCE CHAMBER DIFFUSION PUMP CONTROL ERROR, CHECK FUSE OR CONTROLLER, WHEN READY TYPE Y"
:GOTO 9500
```

```
9450 GOTO 8850
9500 A$=INKEY$ :IF A$="" THEN 9500
9550 IF A$<>"Y" THEN 9400
9600 GOTO 8850
9650 IF KS1=1 THEN 10000
9700 IF KS1=0 THEN PRINT #1,CHR$(KCONT);CHR$(KCH1);CHR$(1); :GOTO 8850
9750 IF KS1=255 THEN PRINT "SOURCE CHAMBER DIFFUSION PUMP CONTROL ERROR, CHECK FUSE OR CONTROLLER, WHEN READY TYPE Y"
:GOTO 9850
9800 GOTO 8850
9850 A$=INKEY$ :IF A$="" THEN 9850
9900 IF A$<>"Y" THEN 9750
9950 GOTO 8850
10000 IF KS2=1 THEN 10350
10050 IF KS2=0 THEN PRINT #1,CHR$(KCONT);CHR$(KCH2);CHR$(1); :GOTO 8850
10100 IF KS2=255 THEN PRINT "TURBO PUMP CONTROL ERROR, CHECK FUSE OR CONTROLLER, TYPE Y WHEN READY " :GOTO 10200
10150 GOTO 8850
10200 A$=INKEY$ :IF A$="" THEN 10200
10250 IF A$<>"Y" THEN 10100
10300 GOTO 8850
10350 CLS :PRINT "NOW BOTH CHAMBER FORELINE PRESSURES ARE OK AND TURBO PUMP AND DIFFUSION PUMPS ARE RUNNING"
10400 PRINT "IF ANY ROUGHING VALES ARE OPEN PLEASE CLOSE THEM AND OPEN MAIN LINE VALVE"
10450 FOR I=1 TO 10000 :NEXT :GOSUB 5750
10500 KCH=64+GATEV :KS=NFTBL(KCH)
10550 IF KS=0 THEN PRINT #1,CHR$(KCONT);CHR$(KCH);CHR$(1); :GOTO 10450
10600 IF KS=1 THEN 10900
10650 IF KS=255 THEN PRINT "TURBO GATE VALVE CONTROL ERROR, CHECK FUSE OR CONTROLLER, HIT Y WHEN READY" :GOTO 10750
10700 GOTO 10450
10750 A$=INKEY$ :IF A$="" THEN 10750
10800 IF A$<>"Y" THEN 10650
10850 GOTO 10450
10900 CLS :PRINT "TURBO GATE VALVE IS OPEN"
10950 PRINT "WAS THIS SYSTEM PUMPING DOWN LONG BEFORE THIS COMPUTER CONTROL TAKES OVER ?"
11000 PRINT "TYPE Y FOR YES OR N FOR NO"
11050 A$=INKEY$ :IF A$="" THEN 11050
11100 IF A$="Y" THEN 11700
11150 IF A$="N" THEN 11400
11200 GOTO 11000
11250 REM---- ---------------------------------------------------------------
11300 REM---- ---- pumps are running and wait for low pressure to turn on gauge
11350 REM---- ---------------------------------------------------------------
11400 PRINT "AFTER 30 MIN. , THE IONIZATION GAUGE WILL BE TURNED ON "
11450 PRINT "RELAX ABOUT 30 MIN AND I WILL LET YOU KNOW WHEN TIME COMES"
```

```
11500 KSTART=PEEK(&H46D)/18.2*256/60+PEEK(&H46E)/18.2*256*256/60
11510 KNOW=PEEK(&H46D)/18.2*256/60+PEEK(&H46E)/18.2*256*256/60
11520 KMIN=KNOW-START :LOCATE 24,30 :PRINT "time since pumps turned on in min. ";KMIN :IF KMIN<30 THEN 11510
11550 PRINT " TO STOP BEEPING, HIT ANY KEY"
11600 BEEP :KL=0 :FOR I=1 TO 3000 :A$=INKEY$ :IF A$<>"" THEN KL=1
11650 NEXT :IF KL=0 THEN 11600
11700 PRINT "Are both ionization gaugages are on ? (y/n)"
11750 A$=INKEY$ :IF A$="" THEN 11750
11760 PRINT A$
11800 IF A$="y" THEN 12000
11850 IF A$="Y" THEN 12000
11900 IF A$="n" THEN 11950
11910 IF A$="N" THEN 11950
11920 GOTO 11700
11950 PRINT "turn on both ionization gauges and hit any key when ready "
11960 A$=INKEY$ :IF A$="" THEN 11960
12000 CLS : PRINT "ion source outgassing procedure has started."
12700 REM---- --------------------------------------------------------
12750 REM---- ---- now ion source and furnace filament outgassing starts
12800 REM---- --------------------------------------------------------
12850 CLS :LOCATE 1,10 :PRINT "********* ion source outgassing ***********"
12900 LOCATE 3,1 :PRINT " please enter "
12950 LOCATE 5,5 : PRINT "source filament min. current in ampere ----"
13000 LOCATE 6,5 :PRINT "source filament max. current in ampere ----"
13050 LOCATE 7,5 :PRINT "source filament current step size ---------"
13060 LOCATE 8,5 :PRINT "front furnace filament min. current in ampere ---"
13070 LOCATE 9,5 :PRINT "front furnace filament max. current in ampere ---"
13080 LOCATE 10,5 :PRINT "front furnace filament current step size --------"
13100 LOCATE 11,5 :PRINT "rear furnace filament min. current in ampere ---"
13150 LOCATE 12,5 :PRINT "rear furnace filament max. current in ampere ---"
13200 LOCATE 13,5 :PRINT "rear furnace filament current step size --------"
13250 LOCATE 5,50 :INPUT SFILMIN
13300 LOCATE 6,50 :INPUT SFILMAX
13350 LOCATE 7,50 :INPUT SFILSTEP
13360 LOCATE 8,55 :INPUT FFILMIN1
13370 LOCATE 9,55 :INPUT FFILMAX1
13380 LOCATE 10,55 :INPUT FFILSTEP1
13400 LOCATE 11,55 :INPUT FFILMIN2
13450 LOCATE 12,55 :INPUT FFILMAX2
13500 LOCATE 13,55 :INPUT FFILSTEP2
13510 LOCATE 15,1 :INPUT "start delay in hours ";SDLY
13520 SDLYSEC=SDLY*3600
```

```
13550 LOCATE 18,20 :PRINT "filament entry all ok ? (y/n) ";
13600 A$=INKEY$ :IF A$="" THEN 13600
13650 PRINT A$ :IF A$="y" THEN 13850
13700 IF A$="Y" THEN 13850
13750 IF A$="n" THEN 12850
13800 IF A$="N" THEN 12850
13850 LOCATE 17,1 :PRINT "******* please turn on printer. hit any key when ready **** "
13860 ON ERROR GOTO 30000
13900 A$=INKEY$ :IF A$="" THEN 13900
13905 KSIX=600/ADFS(1)*DAFTR(1) '----anode current 600 ma
13950 LOCATE 17,1 :PRINT " ";
13952 DLYCNT=0
13954 LOCATE 23,10 :PRINT "delay count down (sec.) :";
13960 K1=PEEK(&H46D)
13968 FOR I=1 TO 12 :NEXT :LOCATE 1,60 :PRINT DATE$;" ";TIME$;
13970 NK1=PEEK(&H46D)
13972 IF K1=NK1 THEN 13968
13976 DLYCNT=DLYCNT+256/18.2
13978 CNTDN=SDLYSEC-DLYCNT :LOCATE 23,40 :PRINT USING "#######";CNTDN;
13980 IF DLYCNT<SDLYSEC THEN 13960
14000 LOCATE 15,1 :COLOR FCOLOR2,BCOLOR2
14050 PRINT "OUTGASSING STARTED AT "; :LOCATE 15,40 :PRINT DATE$,TIME$
14100 LOCATE 17,5 :PRINT "GHP PRESSURE ------------------"
14150 LOCATE 18,5 :PRINT "SOURCE CHAMBER PRESSURE ----------"
14152 LOCATE 19,5 :PRINT "T. CH. FORELINE PRESSURE ----------"
14154 LOCATE 20,5 :PRINT "S. CH. FORELINE PRESSURE ----------"
14200 LOCATE 22,5 :PRINT "S. FIL. AMPERE / VOLT -------------"
14250 LOCATE 23,5 :PRINT "furnaces -------------"
14260 LOCATE 24,5 :PRINT "ANODE mAMP / VOLT ---------------";
14300 COLOR FCOLOR2,BCOLOR2
14350 GHPMAX=100 :SCHMAX=-4 :TMIN=15 '----100 mTorr,1 X -4,15 min
14400 KO=PEEK(&H46C) :K1=PEEK(&H46D) :K2=PEEK(&H46E) :K3=PEEK(&H46F)
14450 SFIL=SFILMIN :TCONT=900 :TPRT=180 '----step up speed 15 min.,print 3min
14500 FFIL1=FFILMIN1
14510 FFIL2=FFILMIN2 :GOSUB 18550
14550 GOSUB 16950
14600 STARTSEC=(K1+K2*256)/18.2*256+KO/18.2
14610 LPRINT CHR$(10)
14612 LPRINT CHR$(10)
14614 LPRINT CHR$(10)
14624 LPRINT CHR$(14);" ION SOURCE OUTGASSING DATA "
14650 LPRINT "outgassing started at ----- ";DATE$,TIME$
```

```
14700 LPRINT "s. fil. min. ,max current and current step --- ";SFILMIN,SFILMAX,SFILSTEP
14750 LPRINT "f. fil. min. ,max current and current step --- ";FFILMIN1,FFILMAX1,FFILSTEP1
14760 LPRINT CHR$(10)
14770 LPRINT CHR$(27);"E"
14780 LPRINT "TIME GHP(mTorr) S.CH.(Torr) S. FIL.(A/V) F/R furnace FRLINE T/S(mTorr)"
14790 LPRINT CHR$(27);"F" :LPRINT CHR$(10)
14800 COUNTOLD=STARTSEC :PRINTOLD=0
14850 KO=PEEK(&H46C) :K1=PEEK(&H46D) :K2=PEEK(&H46E) :K3=PEEK(&H46F)
14900 COUNTNEW=(K1+K2*256)/18.2*256+KO/18.2
14910 IF COUNTNEW<COUNTOLD THEN COUNTOLD=COUNTNEW :PRINTOLD=COUNTNEW
14950 PASSEC=COUNTNEW-COUNTOLD :PASPRINT=COUNTNEW-PRINTOLD
14960 IF KAI<550 THEN 15000 '----anode current above 550 ma, beep
14962 LOCATE 2,5 :PRINT "Arc has struck. Ion source ready. Hit any key to load MASTER.";
14964 LPRINT "Arc has struck at ";TIME$;
14966 LPRINT "outgassing is over and MASTER is loaded at your request."
14970 FOR I=1 TO 100 :BEEP :NEXT
14980 GOTO 16760 '----turn off filaments
15000 IF PASPRINT<TPRT THEN 15100
15050 PRINTOLD=COUNTNEW
15060 LPRINT TIME$;
15062 LPRINT USING "###.#";GRDATA;
15064 LPRINT USING "##.# x";KDATAM;
15066 LPRINT USING " ##";REXP;
15068 LPRINT USING " ##.#A x";R1; :LPRINT USING " ##.#V";R2;
15070 LPRINT USING " ##.#A /";R3; :LPRINT USING " ##.#A x";R4; :LPRINT USING " ##.#V";R5;
15072 LPRINT USING " ###.# /";KTFORL; :LPRINT USING " ##.#";KSFORL
15100 IF PASSEC>>TCONT THEN 16150 '----15 min. interval
15150 KO=PEEK(&H46C)
15200 OLDSEC=KO
15250 KO=PEEK(&H46C)
15300 NEWSEC=KO :NSEC=INT((NEWSEC-OLDSEC)/(8.2*3)) :IF NSEC=0 THEN 15250
15350 GOSUB 16950
15400 IF REXP<-4 THEN 14850
15450 LOCATE 23,1 :PRINT "s. ch. pressure too high, outgassing interrupted.";DATE$,TIME$;
15550 PRINT #1,CHR$(KCONT);CHR$(3);CHR$(0);
15650 PRINT #1,CHR$(KCONT);CHR$(5);CHR$(0); '----turn off both filaments
15660 PRINT #1,CHR$(KCONT);CHR$(6);CHR$(0); '----turn off both filaments
15700 KO=PEEK(&H46C)
15750 KOLDSEC=INT(KO/(18.2*2))
15800 KO=PEEK(&H46C)
15850 NEWSEC=INT(KO/(18.2*2)) :IF NEWSEC=OLDSEC THEN 15800
15900 GOSUB 16950
```

```
15950 IF REXP>>-7 THEN 15700
16000 LPRINT "outgassing restatred at ---- ";DATE$,TIME$
16050 LOCATE 23,1 :PRINT "outgassing resumed at ";DATE$,TIME$;
16100 GOTO 14850
16150 COUNTOLD=COUNTNEW
16200 IF REXP>>-6 THEN 14850
16250 IF SFIL>>SFILMAX AND FFIL1>>FFILMAX1 THEN 16550
16300 IF FFIL1>>FFILMAX1 THEN FFIL1=FFILMAX1 :GOTO 16650
16310 IF FFIL2>>FFILMAX2 THEN FFIL2=FFILMAX2 :GOTO 16650
16350 IF SFIL>>SFILMAX THEN SFIL=SFILMAX :GOTO 16650
16400 BEEP :GOSUB 18650 '----increase current
16450 GOTO 14850
16500 REM---- -- outgassing is over
16550 FOR I=1 TO 1000 :BEEP :NEXT
16650 COLOR FCOLOR3,BCOLOR3 :LOCATE 1,1 :PRINT "outgassing is over at --";DATE$,TIME$
16700 LPRINT CHR$(10)
16750 LPRINT "outgassing is over at --";DATE$,TIME$
16760 SFIL=0 :FFIL1=0 :FFIL2=0 '----turn off filaments
16770 GOSUB 18550
16800 STOP
16900 REM---- ------------------
16950 REM---- --- subroutine outgassing data updating
17000 REM---- -------------------
17050 N=LOC(1) :IF N>>0 THEN A$=INPUT$(N,1)
17100 PRINT #1,CHR$(KTXCTL);CHR$(KTXCTL);CHR$(KTXCTL);
17150 COLOR FCOLOR3,BCOLOR3
17200 N=LOC(1) :IF N<51 THEN 17200 '----32+16+3 BYTES READY ?
17250 N1=ASC(INPUT$(1,1)) :IF N1=KFIRST THEN 17400
17300 N=LOC(1) :IF N>>0 THEN 17250
17350 GOTO 17050 '----TRY TO GET DATA AGAIN
17400 N2=ASC(INPUT$(1,1)) :IF N2=KSECOND THEN 17500
17450 N=LOC(1) :A$=INPUT$(1,N) :GOTO 17100 '----if second byte not correct try again
17500 NMOD=ASC(INPUT$(1,1)) '---- BEAM SWITCHING MODE
17510 N=LOC(1) :IF N<49 THEN A$=INPUT$(1,N) :GOTO 17100
17550 FOR I=1 TO 32
17600 K=ASC(INPUT$(1,1)) :ADTNEW(I)=K :NEXT
17650 FOR I=1 TO 16
17700 K=ASC(INPUT$(1,1)) :NFTBL(I)=K :NEXT
17750 K=ASC(INPUT$(1,1)) :IF K<>>KLAST THEN 17050
17800 LOCATE 1,60 :PRINT DATE$;" ";TIME$
17850 LOCATE 17,40 :RDATA=ADTNEW(8)*ADFS(8)
17900 IF RADATA<.5 THEN GRDATA=10 (RDATA*1.7067)*10 :GOTO 18000
```

```
17950 GRDATA=10 (RDATA*1.09)*20
18000 GRDATA=INT(GRDATA) :PRINT USING "####.# mTorr";GRDATA;
18050 LOCATE 18,40 :RDATA=ADTNEW(30)*ADFS(30)
18100 KDATAM=INT(RDATA) :REXP=KDATAM-8 :DATAM=RDATA-KDATAM :DATAM=10 DATAM :KDATAM=CINT(DATAM) :PRINT USING "##.# x
";KDATAM; :PRINT USING "## Torr";REXP;
18110 LOCATE 19,40 :RDATAM=ADTNEW(31)*ADFS(31)
18122 RDATAM=10 (2.5-RDATAM)*5
18130 KTFORL=CINT(RDATAM) :PRINT USING "####.# mTorr ";KTFORL;
18132 LOCATE 20,40 :RDATAM=ADTNEW(32)*ADFS(32)
18136 RDATAM=10 (2.5-RDATAM)*5
18140 KSFORL=CINT(RDATAM) :PRINT USING "####.# mTorr ";KSFORL;
18150 LOCATE 22,40 :RDATA1=ADTNEW(4)*ADFS(4) :RDATA2=ADTNEW(5)*ADFS(5)
18200 R1=RDATA1*100 :R1=CINT(R1)*.01 :R2=RDATA2*100 :R2=CINT(R2)*.01
18250 PRINT USING "##.# amp. x ";R1; :PRINT USING "##.# volt";R2;
18300 LOCATE 23,15 :RDATA1=ADTNEW(6)*ADFS(6) :RDATA2=ADTNEW(7)*ADFS(7)
18350 R3=RDATA1*100 :R3=CINT(R3)*.01 :R4=RDATA2*100 :R4=CINT(R4)*.01
18360 RDATA3=ADTNEW(23)*ADFS(23)*100 :R5=CINT(RDATA3)*.01
18400 PRINT USING " front : ##.# amp. x /";R3; :PRINT USING " rear : ##.# amp. x";R4; :PRINT USING "##.# volt";R5;
18410 LOCATE 24,40 :ANODV=ADTNEW(3)*ADFS(3) :ANODI=ADTNEW(1)*ADFS(1)
18420 KAV=CINT(ANODV) :KAI=CINT(ANODI)
18430 PRINT USING "####.# mA x ";KAI; :PRINT USING "###.# volt ";KAV;
18450 RETURN
18500 REM----
18550 REM---- --- filament current control -----------
18600 REM----
18650 DAREF=SFIL/ADFS(4) :IDAR=CINT(DAREF) :IF IDAR>>255 THEN 18850
18700 DACONT=DAREF*DAFTR(4)+DASHFT(4) :IDACON=CINT(DACONT) :IF IDACON>>255 THEN 18850
18800 PRINT #1,CHR$(KCONT);CHR$(3);CHR$(IDACON);
18850 DAREF=FFIL1/ADFS(6) :IDAR=CINT(DAREF) :IF IDAR>>255 THEN 19050
18900 DACONT=DAREF*DAFTR(6)+DASHFT(6) :IDACON=CINT(DACONT) :IF IDACON>>255 THEN 19050
19000 PRINT #1,CHR$(KCONT);CHR$(5);CHR$(IDACON);
19050 SFIL=SFIL+SFILSTEP :FFIL1=FFIL1+FFILSTEP1
19060 IF SFIL<0 THEN SFIL=0
19070 IF FFIL1<0 THEN FFIL1=0
19072 DAREF=FFIL2/ADFS(7) :IDAR=CINT(DAREF) :IF IDAR>>255 THEN 19100
19074 DACONT=DAREF*DAFTR(7)+DASHFT(7) :IDACON=CINT(DACONT) :IF IDACON>>255 THEN 19100
19076 PRINT #1,CHR$(KCONT);CHR$(6);CHR$(IDACON);
19078 FFIL2=FFIL2+FFILSTEP2
19080 IF FFIL2<0 THEN FFIL2=0
19100 RETURN
30000 FOR I=1 TO 10 :BEEP :FOR J=1 TO 1000 :NEXT :NEXT
30010 IF ERR=24 THEN LOCATE 25,1 :PRINT "turn printer on "; :RESUME NEXT '----t.o
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```
30012 IF ERR=25 THEN LOCATE 25,1 :PRINT "turn printer on "; :RESUME NEXT '----fault
30014 IF ERR=27 THEN LOCATE 25,1 :PRINT "more printer paper please "; :RESUME NEXT '----paper
30020 PRINT "unidentified error except printer time out ocurred. excecution stopped"
30030 STOP
```

# XIV. VITA

# VITA

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Samsung Electron Devices Ltd. Korea, 1970-1975

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